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Is Polylactic Acid Saving the World?

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Introduction

Plastic utensils are tools that often get thrown away or recycled after one use. A common misconception is that all plastic can simply be recycled and used again; however, there are multiple types of plastic, and different kinds of plastic are broken down at different rates. Polylactic acid, better known as PLA, is a biodegradable plastic made from the sugars of corn starch, cassava, or sugarcane (Cho, 2017). Being biodegradable means that PLA can be broken down in water, carbon dioxide, and compost completely by microorganisms under the right conditions (Cho, 2017). Even though this sounds like a fix to the issue of plastic, it brings up the question of just how much more biofriendly is PLA versus an average biofuel plastic? In order to determine the environmental benefits of PLA, an investigation of material sourcing, production, and disposal of the bioplastic was conducted.

Process Description

When considering the lifecycle of PLA it is necessary to consider 5 main steps. The steps include a lifecycle consideration from both a processing and a consumer standpoint. (Marao & de Bie, 2019) The main lifecycle steps of PLA can be seen below and can be viewed visually in figure one.

1. Sugarcane Harvesting
2. Processing
    - Conversion of sugarcane into raw sugar
    - Fermentation of raw sugar to produce lactic acid
    - Conversion of lactic acid into lactide and PLA
    - PLA formation into desired end product
3. Transportation
    - Sugarcane to processing plant
    - PLA to processing facilities
    - Product to consumer
4. Consumer usage
    - Used for medical devices, 3D printing, and food packaging
    - Not effective for high temperature applications
5. Disposal (Barrett, 2019)
    - Industrial composting: allows for degradation of PLA in a few months
    - Landfill or home composting: Similar degradation as standard, non-biodegradable plastics

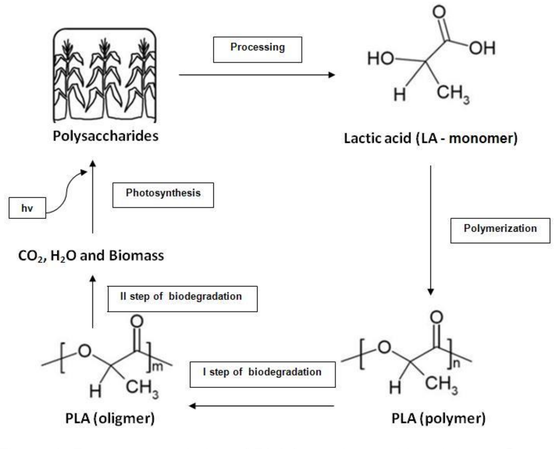

Figure 1. Process description of PLA formation and breakdown Source: Guzman et al., 2011

Ecological Impact

Although bioplastics like PLA may sound like a good alternative to traditional plastics, PLA still has a negative effect on ecosystems and the environment. For example, PLA must be kept separate from traditional plastics when recycled, meaning recycling PLA is not very practical (Toor, 2019). Also, PLA can only be composted in industrial facilities under highly specific conditions (Anderson & Shenkar, 2021). Below are some important fast facts about the ecological impact of PLA.

PLA in Landfills

- PLA that is discarded into landfills could take up to 1000 years for to decompose. *NatureWorks*, one of the world's largest producer of PLA, has accepted that their products will not fully break down in landfills (Toor, 2019)
- When PLA is in an anerobic landfill environment, it generates significant methane quantities (Krause & Townsend, 2016).

PLA's Impact on Different Ecosystems

- The impact of bioplastics on marine environments is currently poorly studied due to bioplastics still being relatively new. However, current studies demonstrate that bioplastics have a similar effect as traditional plastics on marine organism fertilization and accumulation (Anderson & Shenkar, 2021).
- An experiment was conducted where PLA microplastics were added to soil and planted with a perennial ryegrass. The outcome showed fewer seeds that germinated and a reduction in shoot height when compared to the control (Boots, et al., 2019).

Water and Carbon Impact

- "From a cradle-to-grave perspective the Global Warming Potential (GWP) of PLA is confirmed to be only 500-gram CO_2 /kg of PLA" says François de Bie, Senior Marketing Director at Total Corbion PLA, "which is roughly a 75% reduction in carbon footprint versus most traditional plastics"(bioplasticsmagazine.com, 2019). The GWP of each step of PLA production is shown in figure 2 below.
- The production of PLA from sugarcane uses ~60 m^3 water/ton PLA (fig. 3) compared to traditional plastic which uses ~168 m^3 water/ ton PLA (Hidden Waters, 2007).

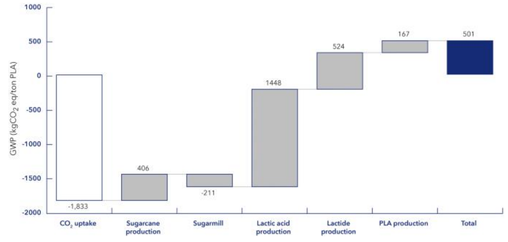

Figure 2. Global Warming Potential (GWP) of the different production steps of PLA from sugarcane. Source: Morao, A. & Francois de Bie, 2019.

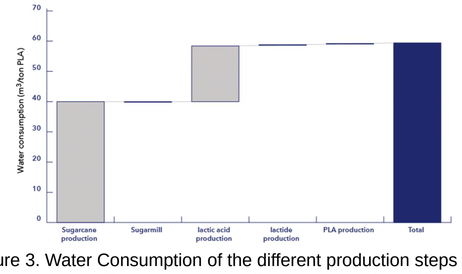

Figure 3. Water Consumption of the different production steps of PLA from sugarcane. Source: Morao, A. & Francois de Bie, 2019.

Sensitive Unit

The full life cycle analysis of PLA reveals many possible units that could heavily influence or ultimately prevent the bioplastic from becoming an environmentally conscious alternative to other petroleum-based plastics. Fortunately, the majority of limitations PLA may have can be traced back to the actual production of the bioplastic. Thus, the unit most sensitive to environmental impact is the unit of production, specifically the blend of various chemicals and polymers added to the PLA product during manufacturing. PLA products are rarely composed of entirely pure PLA, but rather a blend of additives; varying from manufacturer to manufacturer, as seen in Figure 4, these additives are designed to improve the brittleness and durability of pure PLA. While the implementation of these compounds may be necessary for production, the effect they have on the environment after disposal is a novel one that largely varies on the type of raw material used.

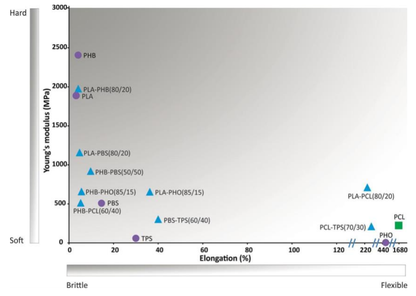

Figure 4. Physical properties of biodegradable plastics (purple circles), fossil-based biodegradable polymers (green squares), and their combined blends (blue triangles). Source: Chaganti et al., 2018

For example, two studies were conducted on various PLA blends to analyze the impact the additives had on disposal and overall degradation rates, as well as possible adverse effects the degraded chemicals had on living systems. Findings included:

- Three blends were unable to biodegrade in an aqueous environment. These results are similar to those of commonly used petroleum based and other non-degradable plastics.
- PLA blended with the polymer polyhydroxyoctanoate (PHO) was found to increase the time required for suitable biodegradation of PLA products twofold.
- PLA blended with the polymer polycaprolactone (PCL) was found to improve biodegradability of the product, allowing the blend to compost in a managed home composting environment that pure PLA was not able to degrade in.
- A majority of the samples contained chemicals that were invasive and capable of inhibiting or triggering various cellular mechanisms.

(Chaganti et al., 2018; Dombrowski et al., 2020)

The possibility of certain PLA products not being biodegradable or releasing chemicals toxic to cells during degradation heavily influences determination of environmental benefits and shortcomings PLA based plastics may have. Thus, the manufacturing of these products, specifically the blends of additives used in production remains the most sensitive unit of the PLA system.

Research

This program will investigate water body pollution due to improper disposal of PLA.

- PLA requires temperatures above 50°C to properly biodegrade. This temperature is almost never reached in natural water bodies. (Anderson & Shenkar, 2021).
- Do the direct impacts of PLA in natural water bodies (Figure 5) differ from petroleum-based plastics?
    - What are the impacts on plants and animals?
    - Do any toxic chemicals leach out of the PLA?

Figure 5. Plastic litter on the shore of a water body. Source: *DW.com*

Suggested Research Program: Fathead Minnow Larval Survival and Growth Toxicity Tests

- Produce a partially degraded sample of PLA.
    - This sample should represent PLA littered on the shoreline of a natural water body.
    - Leave the plastic immersed in water, exposed to outdoor elements, for a long period of time.
- Grow fathead minnows in a tank with the partially degraded PLA suspended in the water, as shown in Figure 6.

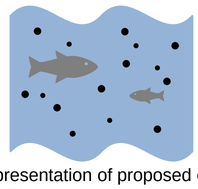

Figure 6. Artistic representation of proposed experiment. Partially degraded PLA shown as black dots in water.

- Analyze the impact of the PLA on minnow growth.
    - The minnows are susceptible to toxic chemicals.
    - Decreased growth may indicate the presence of toxic chemicals leaching from the PLA.

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