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Are Polymers Toxic? Case Study: Environmental Impact of a Biopolymer

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Abstract: In this paper, the analysis of the environmental impacts of a biopolymer based on starch is presented. These impacts were calculated from a cradle to gate LCA (Life Cycle Assessment), based on UNEEN ISO 14040: 2006 and UNEEN ISO 14044, using as functional unit 1 kg of produced biomaterial. The impact categories analyzed were global warming, ozone depletion, acidification and eutrophication. The results indicate that the electricity causes the highest impacts in the global warming and ozone depletion categories, but compared to synthetic polymers, the emissions are low. Finally, in the case of eutrophication, the impacts are similar to other biopolymers but higher in comparison with petroleum-based polymers like HDPE (High Density Polyethylene), LDPE (Low Density Polyethylene), PP (Polypropylene), PS (Polystyrene) and PET (Polyethylene Terephthalate).

Key words: Polymer, biopolymer, LCA, environmental impacts.

1. Introduction

Synthetic polymers known generically as plastics are produced from basic raw materials, called monomers, which are subjected to specific chemical reactions (polymerization, polycondensation and polyaddition) under particular conditions. Their marketing is given of powders, granules, flakes, liquids or suspensions, products, containers, bottles, etc. [1].

Plastics are able to adopt different forms such as bags, bottles, jars, thin films and pipes, among others. In addition, they are thermal and electrical insulators resist corrosion and other chemical factors and are easy to handle, so they have had a diffusion and been used in almost all areas of human activity [1, 2].

Despite its indisputable utility in everyday life, once the plastics have been used, they become waste. It is estimated that 25 million tons of plastics accumulate in the environment every year and can remain unchanged for a period of between 100 and 500 years, since its degradation is very slow and consists in its fragmentation in the smaller particles. These particles originate problems of water, air and soil contamination that impacts directly to the environment and health. In addition, the highest percentage of plastics is produced from fossil fuels, which causes excessive pressure on non-renewable energy sources [2].

Due to the above, the so-called biopolymers have been developed, which present physicochemical and thermoplastic properties similar to petroleum based polymers with the difference of being biodegradable [3]. However, various questions and challenges arise around the use of these materials, since the fact that they are based on renewable raw materials does not imply that they are sustainable [4]. Therefore, it is necessary to carry out studies that allow to know the potential environmental impacts of the new biopolymers developed, for which it can use the LCA

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(Life Cycle Assessment).

The LCA methodology is an environmental management tool for "collecting and evaluating the inputs, results and potential environmental impacts of a system or product during its life cycle" [5].

LCA can assist in identifying opportunities to improve the environmental aspects of products at various points in their life cycle; in decision-making in both industry and government and non-governmental organizations (e.g. strategic planning, prioritization, design or redesign of products or processes); in the selection of relevant environmental performance indicators, including measurement techniques; and marketing (for example, an environmental statement, an environmental seal or eco-labeling scheme, or an environmental statement of product).

The ISO (International Organization for Standardization) has established a framework for the standardization of LCA methodology, according to the ISO 14040 family of standards [6]:

- UNEEN ISO 14040: 2006: Environmental management. Life Cycle Assessment: principles and frame of reference.
- UNEEN ISO 14044: 2006: Environmental management. Life Cycle Assessment: requirements and guidelines.

According to the standardization, four phases are distinguished in a LCA study: definition of scope and objective, inventory analysis, impact assessment and interpretation. Although the stages of the LCA are described in a linear way, they are not carried out in such a way, as shown in Fig. 1 that is an iterative process that can go from one phase to another when required.

For all of the above, the present study carried out the LCA of a biopolymer based on starch, which allowed to identify potential environmental impacts throughout its production and to verify if these impacts are lower than those from synthetic polymers.

2. Material and Methods

The life cycle analysis was performed based on ISO standards (Fig. 1).

2.1 Definition of Goal and Scope

It was defined the objective and the scope according to the system boundaries, functional unit and flows within the life cycle and quality required of the data.

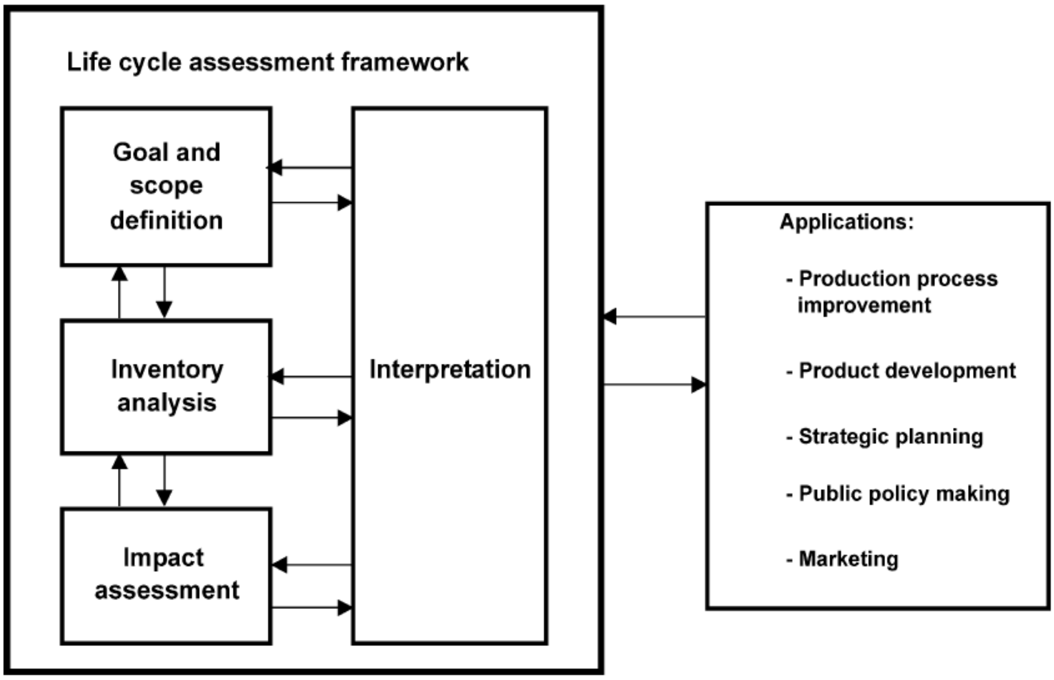

Fig. 1 Life Cycle Assessment phases [7].

Ecoinvent database was used to carry out the LCA; this is the world leader with consistent and transparent life cycle inventories of more than 4,000 processes. Scenario data are based on industrial information and have been compiled by various internationally recognized research institutes and LCA consultants. Data are available in EcoSpold data format and are compatible with leading LCA and eco-design software tools [8].

2.2 Development of the LCI (Life Cycle Inventory)

The data corresponding to the inputs and outputs were collected for all the processes of the product system. The scenario was elaborated based on primary information from laboratory analysis, secondary information obtained through a rigorous bibliographic review and databases related to the productive processes involved with such a system.

Information about the production of water, corn starch and sodium borate was taken directly from the Ecoinvent database. In the case of casein, a scenario was established for acid precipitation based on literature.

On the other hand, the electrical energy used for gelatinization of starch in mixture 4 was calculated based on the LCA study performed by Madival, S. et al. [9], using the specific heat of water and the starch gelatinization enthalpy. Likewise, the electrical energy for heating the mixtures in both scenarios (biomaterial production and casein production) was calculated taking into account the specific heat of whole milk.

Finally, the required energy for agitation, drying and centrifugation was obtained directly from the specifications of the laboratory equipment and the operating time. Once the inputs and outputs of the system have been established, the necessary quantity of each one was calculated for the production of 1 kg of biomaterial.

2.3 LCIA (Life Cycle Impact Assessment)

The inventory of inputs and outputs was transferred to indicators of potential environmental impacts to the environment using the software SIMAPRO^{TM}, a commercial tool developed by Pré, C. [10] which analyzes and compares the environmental aspects of a product or process in a systematic and consistent way, complying with the recommendations of ISO 14040 and ISO 14044.

The impact categories studied were global warming, ozone depletion, acidification and eutrophication using the method TRACI 2.1 (The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts).

2.4 Interpretation

The results of the LCI and the LCIA were interpreted according to the objective and scope initially marked and the conclusions were drawn.

3. Results

3.1 Definition of Goal and Scope

The general objective of the LCA was to assess the potential environmental impacts generated during the manufacture of a biopolymer based on starch.

The system studied has the function of manufacturing a biomaterial and consists of two phases. In phase 1, the production of the reinforcement is carried out; in phase 2, the reinforcement is mixed with gelatinized corn starch for the production of the biomaterial.

The functional unit used for the analysis was established as 1 kg of produced biomaterial. The system boundaries were defined as from the cradle to the gate, taking into consideration the production of raw materials and the manufacture of reinforcement and biomaterial, excluding the stages of usage and end of life of the product.

3.2 Development of the LCI

Fig. 2 schematically represents the inputs and outputs of the biomaterial production process.

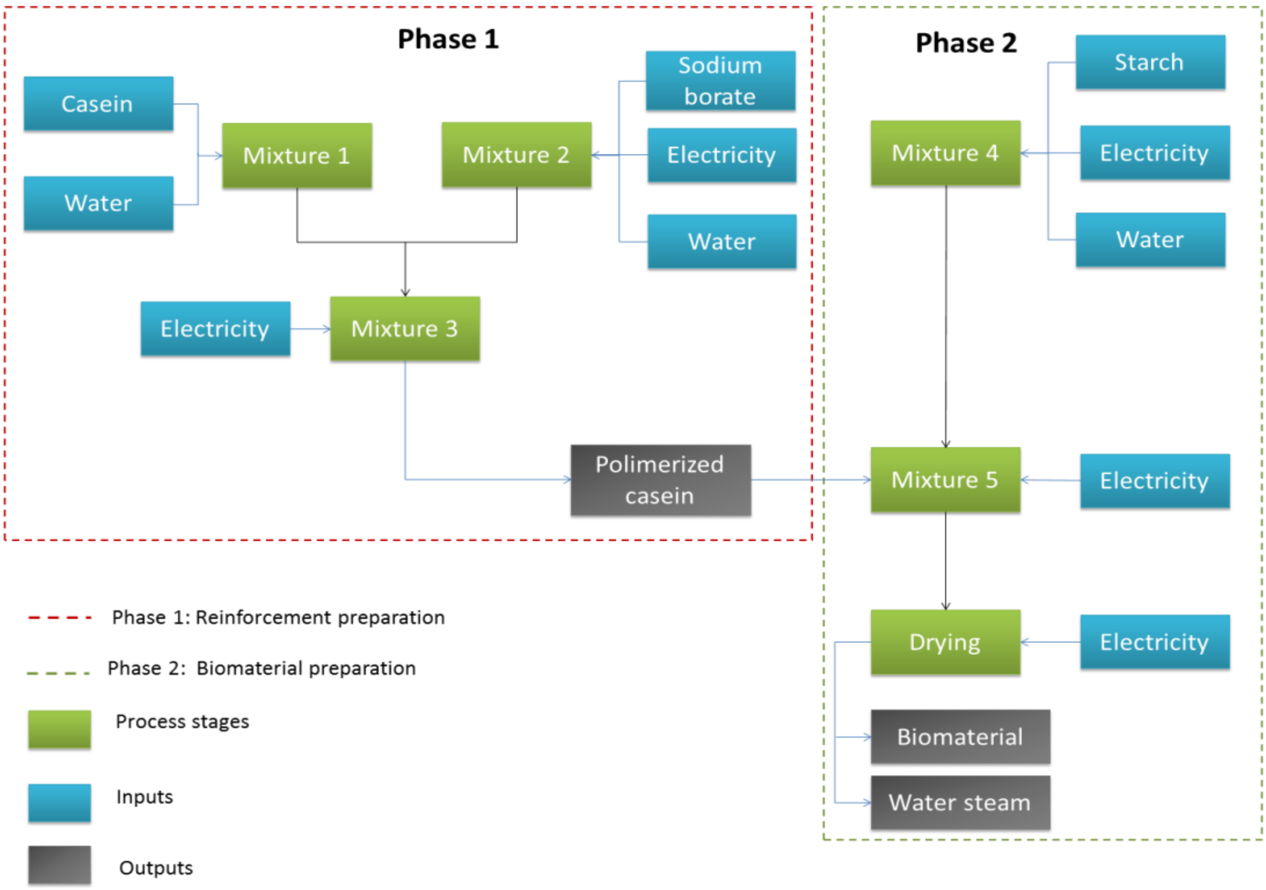

Fig. 2 Biomaterial production process.

Table 1 Summary of inputs and outputs of the biomaterial production system.

Phase	Stage	Inputs			Outputs		
Phase 1	Mixture 1	Casein	130	g			
		Water	410	g			
	Mixture 2	Sodiumborate	50	g			
		Water	410	g			
		Electricity	0.08	KWh			
	Mixture 3	Electricity	0.04	KWh	Polimerizedcasein	1,000	g
Phase 2	Mixture 4	Starch	342.86	g			
		Water	514.29	g			
		Electricity	0.11	KWh			
	Mixture 5	Polimerizedcasein	571	g			
		Electricity	0.27	KWh	Watersteam	428	g
	Drying	Electricity	0.50	KWh	Biomaterial	1,000	g

The inputs and outputs of the system are summarized in Table 1.

3.3 LCIA

The impacts generated by the manufacturing of biopolymer are summarized in Table 2, as it can be observed the major impact is caused in the category of global warming.

Fig. 3 shows the percentage contribution of each process stage to impact categories. The graphic shows that all the impacts are indirect, because they do not come from the manufacturing of the biomaterial but

Table 2 Potential impacts generated by the manufacturing of biopolymer.

Impactcategory	Total	Unit
Ozone depletion	1.20 E-07	Kg CFC-11 eq
Global warming	1.524	Kg CO_2 eq
Acidification	0.009	KgSO_2 eq
Eutrophication	0.017	Kg N eq

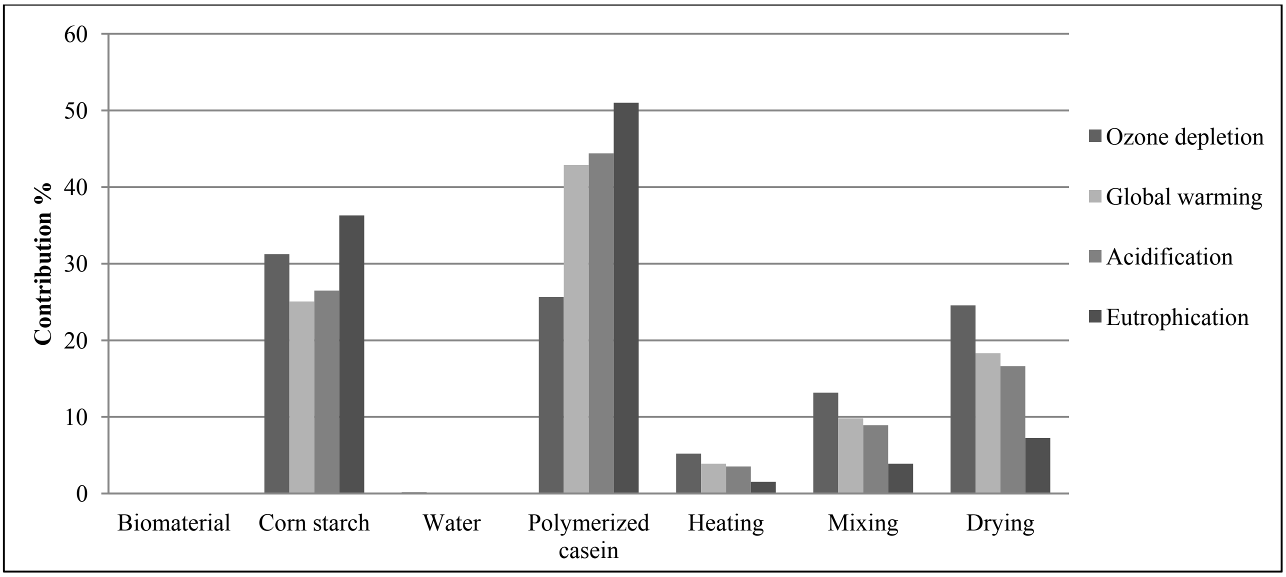

Fig. 3 Contribution per stage to the impact categories.

from the production of raw materials. The stages that contribute the most to the four impact categories are the production of polymerized casein, corn starch and the energy required for drying.

The impacts in global warming, ozone depletion and acidification categories come principally from the use of fossil energy, as natural gas, to generate the electricity. In the case of eutrophication, the principal contributors are the manure and fertilizers used in the crop of corn and other crops to feed the cattle that produce the milk for casein.

Emissions generated in the climate change category are lower compared to other biopolymers and petroleum-based polymers such as PLA (Polylactic Acid), PHA (Polyhydroxyalkanoate), TPS (Thermoplastic Starch), HDPE (High Density Polyethylene), PP (Polypropylene) and PS (Polystyrene) analyzed by Vink, E. T. et al. [7] and Hottle, T. A. et al. [11], who defined as limits of the system from cradle to gate and reported emissions of 1.5 to 3.5 kg CO_2 eq/kg of produced material.

Similarly, the impacts generated in the category of ozone depletion are lower than those obtained by Vink, E. T. et al. [7] and Hottle, T. A. et al. [11], where data are reported between 1.5×10^{-7} and 4×10^{-7} kg CFC-11 eq/Kg of polymer.

Finally, in the case of eutrophication, the impacts are similar to other biopolymers, since Vink, E. T. et al. [7] and Hottle, T. A. et al. [11] report emissions of 0.010 to 0.025 kg N eq. On the other hand, in comparison with petroleum-based polymers, the impacts are higher since Hottle, T. A. et al. [11] report emissions lower than 0.010 kg N eq for HDPE, LDPE (Low Density Polyethylene), PP, PS and PET (Polyethylene Terephthalate).

4. Conclusions

Under the conditions described throughout the study, the manufacturing of the biomaterial impacts principally in the global warming category, producing a total of 1.524 kg CO_2 eq/kg of biomaterial, being the polymerized casein, the one with the greatest contribution, because of the heating of solutions. However, the emissions are lower compared to other biopolymers.

Although the impacts of the biopolymer compared to conventional materials are lower in the global warming and ozone depletion categories, there is a greater impact on eutrophication, so it is necessary to carry out studies of LCA including the stages of use and final disposal of the biopolymers, to verify if, as expected, they generate a smaller impact compared to polymers based on non-renewable raw materials.

LCA allows the identification of the potential environmental impacts of biopolymers and allows decisions to be taken to improve production processes.

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