LCA of biodegradable multilayer film from biopolymers

Daniel Garraín[1], Rosario Vidal[1], Pilar Martínez[2], Vicente Franco[1], David Cebrián-Tarrasón[1]
[1]GID, Engineering Design Group, Dpt. MEC, Universitat Jaume I Castellón
Av. Sos Baynat s/n, 12071 Castellón (Spain)
[2]AIMPLAS, Technological Institute of Plastics
València Parc Tecnològic, C/ Gustave Eiffel, 4, 46980 Paterna-Valencia (Spain)
garrain@uji.es

Keywords: Biopolymer, LCA, biodegradable, environmental impact, multilayer film

ABSTRACT

Multilayer films exhibit excellent properties for food packaging. However, existing products are not biodegradable. Conventional plastics, manufactured from fossil fuels, not only consume non-renewable and finite resources, but also impact heavily on waste disposal.

A new multilayer film has been developed in the Multibio Project for the production of food packaging. In this paper, the environmental impacts of this new biodegradable multilayer film -based on modified starch and polylactic acid (PLA)- and those of the conventional multilayer film -based on PP and PA6- are quantified in the categories of climate change, fossil fuel depletion, acidification and eutrophication. The Multibio multilayer film is shown to nearly halve the impact of its conventional counterpart.

Introduction

Consumer interest in biodegradable materials has grown as a consequence of increasing social awareness of the power to reduce environmental degradation by selecting more environmentally-friendly products.

Some authors [1-4] have noted that biodegradable materials are, in some cases, less 'ecological' than conventional ones. This is -among other reasons- due to the high degree of optimization of conventional industries; biopolymers obtained from renewable sources are still in an incipient state of development as compared to petroleum-derived plastics. The environmental impact of biopolymers is high nowadays, albeit improvable. Therefore, further research on their optimization towards their environmental improvement should be conducted [5].

In recent years, multilayer films have become increasingly important for many applications, especially in the food industry, where they are mainly applied to the packaging of products such as fresh pasta, meats and cut vegetables to extend the shelf-life of goods. Commercial multilayer films currently comprise a number of layers (3–9) of different polymers. In most applications, the outer layers consist of cheap, water barrier polymers with good mechanical properties; the inner layers consist of more expensive materials, which offer good gas-barrier properties. These conventional multilayer films are not biodegradable.

Goal, scope and functional unit

The main goal of our study is to carry out a first assessment of the environmental impact of a biodegradable multilayer polymer derived from carbohydrate polymers using LCA. This assessment will allow us to find out which life-cycle phases and materials of the multilayer polymer should be improved, and to identify the aspects that require further research from an environmental viewpoint. The product developed is an innovative 100% biodegradable multilayer sheet for its application in single-use food packaging obtained from potato and corn starch, presented as an alternative to the existent non-biodegradable containers. It is composed of three layers: two outer layers made from PLA (Polylactic acid) and one inner layer from compounding of modified starch, PCL (Polycaprolactone) and glycerol monostearate (PLA-Starch-PLA). This sheet is compared to a functionally similar multilayer PP - PA6 (Polyamide Nylon 6) - PP sheet.

The functional unit considered is 1 m^2 of packaging film of similar thickness (each layer in microns): 25-200-50 for the biodegradable multilayer film (68% in weight for compounding starch and 32% for PLA) and 130-20-130 for the conventional multilayer film (91% in weight for PP and 9% for PA6). In the comparison between the two multilayer films, it is assumed that quality in the preservation of pasta is not significantly lost.

Life Cycle Inventory

A life Cycle Inventory (LCI) has been determined for each of the constituents of the multilayer material, based mainly on bibliographic information. Energy data and flux diagrams of the required production processes -from the processing of grains to the thermo-forming of the packaging- have been taken from the measurements made in a pilot plant.

The inventory analysis used for PP and PA6 was provided by PlasticsEurope [6]. The biodegradable multilayer film is composed of PLA in the two external layers and compounding of modified starch with polycaprolactone (PCL) in the inner layer. The life cycle inventory for PLA was taken from [7], with the addition of the use of fertilizers for corn cultivation that were taken from [8]. Other literature considered included [9] which provided results for energy consumption similar to results presented by [7] and the environmental impacts for maize culture in [10].

Modified starch was obtained from a blend of starches, 50% in weight of potato starch (21% amylose) and 50% in weight of Hylon VII (70% amylose) obtained from corn. Chemical modification of the starch was conducted in a laboratory test in the BioComposites Centre (University of Wales, UK).

The environmental impacts of the different starches are obtained from the life cycle inventory in [11] and contrasted with the data supplied by [12]. To modify the starch, lauroyl chloride derived from vegetable oils was used. Its environmental impacts were obtained mainly from [13]. The greenhouse effect has a very high score as a consequence of N_2O emissions, about which there is great uncertainty because they depend on the type of soil, climate, etc. [13-16]. In this study, the corrections introduced by [16] to estimate the amount of N_2O emissions were considered.

Derivatives of vegetable oils showed the greatest uncertainties in this study. It should also be taken into account that the oleo-chemical sector is not –generally speaking- at the same level of optimisation as the polymer sector, which means that the impacts will get lower as the former evolves. Likewise, LCA studies on the production of vegetable oils and their derivatives are significantly less widespread and optimised than those on the production of polymers.

The life cycle inventory for PCL, needed for compounding with the modified starch, was obtained from [17].

The manufacturing of the biodegradable and conventional multilayer films has been tested at a pilot plant owned by AIMPLAS and the electricity consumption has been measured directly.

The manufacturing of the biodegradable film comprises the co-extrusion of the starch compound with previously dehumified PLA, after which the resulting co-extruded multilayer sheet is thermoformed to produce the packaging.

The process is similar for the conventional multilayer film, although energy requirements are higher due to the higher melting point of PP and PA6 as compared to PLA and modified starch. The energy model used was obtained from the Union for the Co-ordination of Production and Transmission of Electricity (UCPTE) for Europe [18].

Neither the impact due to transport from production plants of individual materials to processing industries nor the impact of transport to consumers was considered.

Disposal assessment

The biodegradability and compostability of the new material and the environmental effect of eliminating the waste of the two multilayer packaging products, especially on the global warming category, were also analysed.

The methodology developed by the European Commission [19] –updated with the characterisation factors in [20]- was applied to three scenarios: incineration without energy recovery, landfill without gas control and composting in simple window systems.

Table 1 compares the CO_2 equivalent emissions of a functional unit of 1 m^2 of multilayer plastic material for the three waste scenarios analysed: incineration, landfill and composting.

The biodegradable multilayer film is the one that performs best at disposal. The environmental impact is the lowest when waste is composted. The environmental impact is higher when the multilayer film uses plastics derived from petroleum. This worsening is more significant if waste is incinerated.

Only in the case of disposal of waste to landfill does the biodegradable multilayer film show a worse environmental behaviour than the conventional material. Methane emissions increase the impacts in the global warming category, whereas conventional multilayer film is not degraded in landfill and thus no emissions are produced.

Table 1. Greenhouse gas (GHG) fluxes (in kg of CO_2 equivalent) for 1 m^2 in different disposal scenarios

	Incineration	**Landfilling**	**Composting**
Conventional film	0.794	0.002	-
Biodegradable film	0.007	0.363	0.074

Results

Table 2 shows the environmental impact of the production of 1 m^2 of both biodegradable and conventional multilayer films.

Impact category	**Unit**	**Biodegradable film**	**Conventional film**
Global warming (GWP100)	Kg CO_2 eq.	1.07	2.04
Acidification	Kg SO_2 eq.	0.00706	0.00548
Eutrophication	Kg PO_4^{3-} eq.	0.000671	0.00028
Fossil energy depletion	MJ	29.1	33.6

The life cycle assessment of the PP-PA6-PP multilayer film includes the production of pellets for each of the polymers, the dehumidification processes for PA6, the co-extrusion of the three layers, the thermo-forming and the incineration in the disposal. In the case of biodegradable multilayer films, besides considering the production of each material, we have also included: the dehumidification of PLA, the chemical modification of starch, the compounding of modified starch with PCL, the co-extrusion of the three layers, the thermo-forming and the composting of the packaging at disposal. The transport from production centres to consumers has not been considered for either of the two multilayer films.

The production of multilayer film from petrochemical polymers exhibits higher environmental impacts than the production of biodegradable multilayer film. The biodegradable multilayer film has lower global warming and fossil energy depletion impacts than the conventional multilayer film. Differences in the acidification category are relatively small. Eutrophication is the sole category for which the conventional multilayer film exhibits a lower impact. This impact is produced by the use of fertilizers for the production of renewable polymers, and could be reduced with the improvement of agricultural practices.

In order to consider the relative importance of these impacts, characterisation values of table 1 are normalised with regard to the values corresponding to West Europe (1995) for the categories of global warming, acidification and eutrophication, and to the world (1999) for the category of fossil fuels depletion of CML 2 baseline method included in the software SimaPro v7.0. Normalised impacts are represented in figure 1.

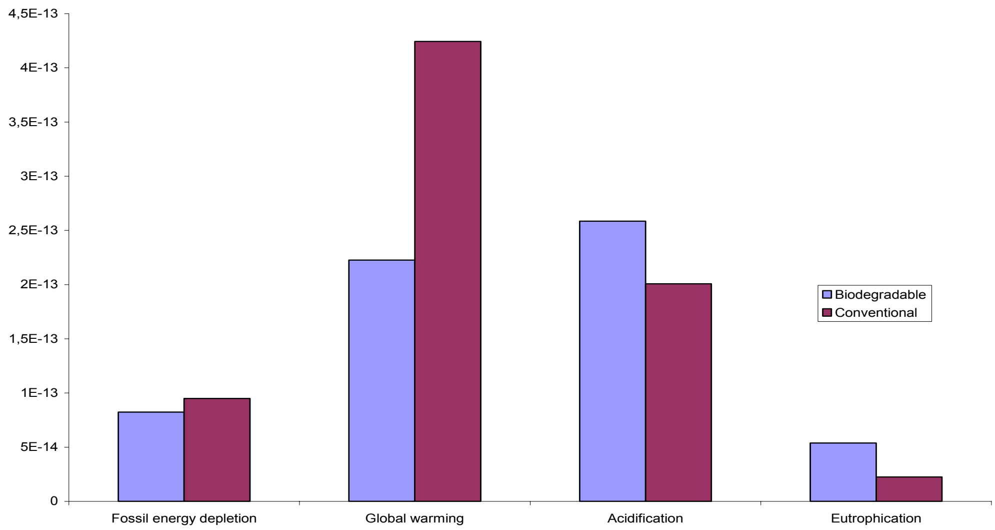

Figure 1. Normalized life cycle assessment of 1 m^2 of multilayer film

Conclusions

The production of multilayer film with petrochemical polymers exhibits a higher environmental impact than the production of biodegradable multilayer film. Global warming is the most significant impact category (as a normalised value). The performance of the biodegradable multilayer film compares favourably to that of conventional multilayer film in this category. Eutrophication is significantly the least important category impact, so even though the biodegradable multilayer film does not perform as well in this category.

The biodegradable multilayer film has lower global warming and fossil energy depletion impacts than the conventional multilayer film. Differences in the acidification category are relatively small. The eutrophication category, with the least relative importance, is the only one for which the conventional multilayer film presents significantly lower impact.

The following clarifications are needed to justify the above conclusions:

- The polyolefin production industry now works with high efficiency rates. The environmental impacts of polyolefins by PlasticsEurope (Association of Plastics Manufacturers) reflect improvements of 45% in energy consumption over the past 10 years.
- Raw materials and biopolymers used in biodegradable multilayer film production have been estimated to produce high impacts, due to the following reasons:
  - The manufacturing and use of fertilizers for crops leads to eutrophication (PO_4^{3-}). Agricultural practices, particularly climate and local differences, should be more accurately known to improve the analysis.
  - The oleo-chemical industry, supplying chemicals like acyl halide for modifying and compounding in biopolymer production, has a lower optimisation degree than the commodity polyolefin industry.
  - Moreover, there is insufficient environment data available in the literature for these phases of the life cycle.
- Impacts of the co-extrusion and thermoforming processes are estimated to be slightly lower for

biodegradable materials in this study, due to lower electricity consumption figures per unit of weight.

- Regarding the global warming category, conventional multilayer film has a 90% higher impact than the biodegradable multilayer film.
- The incineration of materials derived from petroleum -like polyolefins- causes a high impact in global warming because all of the fossil carbon is discharged as CO_2. However, composting biodegradable multilayer film has no estimated effect in the balance of CO_2 because the carbon released re-enters the natural carbon cycle after having been absorbed during plant growth.

Acknowledgements

This work has been developed as a part of these projects:

- MULTIBIO: Craft Project of 5th Framework Programme: contract n. QLK5-CT-2002-71148. “Development and optimisation of a 100% biodegradable and cheap multilayer sheet, for its application in single use packaging”.
- National Environmental Science and Technology Programme of the R&D National Programme 2004-2007 (Ministry of the Environment of Spain): Reference 566/2006/1-2.4. *“Análisis del ciclo de vida de residuos de materiales biodegradables y biocompuestos, como alternativa a los polímeros convencionales (Life cycle assessment of the waste of biodegradable materials and biocomposites, as an alternative to conventional polymers)”.*

References

[1] Gärtner S.O., Reinhardt G.A. Biobased products and their environmental impacts with respect to conventional products. In Proceedings of the 2nd World Conference on Biomass for Energy, Industry and Climate Protection, Rome, 2004.

[2] Braschkat J., Gärtner S.O., Reinhardt G.A. Environmental impacts of bio-based products in comparison with conventional products. Agroindustria, Ed. Ranalli, Bologna, 2004, Vol.2, pp. 53-59.

[3] Patel M., Bastioli C., Marini L., Würdinger G.E. Life-Cycle Assessment of Bio-Based Polymers and Natural Fibres. Encyclopedia “Biopolymers”, 2003 Vol.10, pp. 409-452.

[4] Scott G. Green polymers. Polymer degradation and stability, 2000, 68, pp. 1-7.

[5] Känzig J., Anex R., Jolliet O. Conference report: International workshop on assessing the sustainability of bio-based products. International Journal of Life-Cycle Assessment, 2003, 8 (5), pp. 313-314.

[6] PlasticsEurope. Assessing the eco-efficiency of plastics packaging waste recovery. PlasticsEurope, 2004.

[7] Vink E.T.H., Rábago K.R., Glassner D.A., Gruber P.R. Applications of life cycle assessment to Nature Works polylactide (PLA) production. Polymer Degradation and Stability 2003 (80):403-419.

[8] James K., Grant T. LCA of degradable plastic bags. Centre for Design at RMIT University, 2005.

[9] Bohlman G.M. Biodegradable packaging life-cycle assessment. Environmental Progress 2004 (4): 23.

[10] Gärtner S.O., Müller-Sämann K., Reinhardt G.A., Vetter R. Corn to plastics: a comprehensive environmental assessment. Institute for Energy and Environmental Research Heidelberg, Institute for Land Management Compatible to Environmental Requirements, 2004.

[11] Dinkel F., Pohl C., Ros M., Waldeck B. Ökobilanz stärkehaltiger Kunststoffe. Bundesamt für Umwelt, Wald end Landschaft (BUWAL), 1996.

[12] Müller-Sämann K., Reinhardt G.A., Vetter R., Gärtner S.O. Nachwachsende Rohstoffe in Baden-Württemberg: Identifizierung vorteilhafter Produktlinien zur stofflichen Nutzung unter besonderer Berücksichtigung unweltgerechter Anbauverfahren. Projektabschluss-bericht Forschungszentrum Karlruhe/ IfUL Müllheim, 2003.

[13] Nielsen P., Nielsen A., Weidema B., Dalgaard R., Halberg N. LCA Food Data Base, 2003.

[14] Patel M. Surfactants based on renewable raw materials. Journal of Industrial Ecology 2004;Volume 7, Number 3–4.

[15] Dall'Acqua S., Fawer M., Fritschi R., Allenspach C. Life cycle inventories for the production of detergents ingredients. EMPA, 1999.

[16] Gärtner S.O., Reinhardt G.A. Life Cycle Assessment of Biodiesel: Update and New Aspects. IFEU-Institute for Energy and Environmental Research, Heidelberg GmbH, 2003.

[17] Esterman R., Schwarzwälder B. Life cycle assessment of Mater-Bi bags for the collection of compostable waste. COMPOSTO for Novamont, 1998.

[18] ETH. Okoinventare fur Energiesysteme. ETH, Switzerland, 1994.
[19] Smith A., Brown K., Olgivie S., Rushtone K., Bates J. Waste Management Options and Climate Change. Culham Abingdon. OX14 3ED: AEA Technology, 2001.
[20] Houghton J.T., Ding Y., Griggs D.J., Noguer M., Linden P., Dai X., Maskell K., Johnson C.A. Climate change 2001: the scientific basis. Cambridge University Press, 2001.