CHEMICAL ENGINEERING TRANSACTIONS

VOL. 75, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Laura Piazza

ISBN 978-88-95608-72-3; **ISSN** 2283-9216

DOI: 10.3303/CET1975033

Environmental Benefits: Traditional Vs Innovative Packaging for Olive Oil

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The olive oil industry is an important sector in Europe, the related production process is characterized by different practices and techniques associated to several adverse effects on the environment, both for the agricultural procedures and for olive oil extraction process. The goal of this work is to develop a new packaging solution to better preserve the oil quality trying to reduce food losses and environmental impact. In detail, a comparison between traditional and innovative packaging was carried out. This work is part of a larger project "Sustainability of olive oil System project (S.O.S.)", financed by *AGER – Agroalimentare e Ricerca*, whose purpose is to improve the environmental sustainability in the olive-oil production system. The traditional packaging considered for the study is a three layers packaging: polyethylene (PE), aluminum, polyethylene terephthalate (PET). Instead, the new solution considered is a three layers packaging made from two bio-based polymers: polylactic acid (PLA) treated with metallization and Bio-polyethylene (BIO PE). To calculate the environmental impact of each packaging, raw materials, instruments and relative energy used to create the films, and material disposal phase were considered. The Life Cycle Assessment (LCA), "from cradle to grave" was used to assess the environmental impact of studied packaging. The functional unit was defined in the single-use packaging (olive oil content equal to 10 ml). Respect to traditional packaging, the innovative one has obtained better performances in the human health impact categories (e.g. climate change -44% CO2 eq). On the other hand, the fermentation process of sugar cane, even if is considered a biological process, showed higher impacts in the ecosystem quality impact categories (e.g. water resource depletion, freshwater ecotoxicity and land use). The final comparison between the two packaging shows that the improvement of environmental sustainability of the innovative packaging is not confirmed for all the impact categories used to assess the environmental impact. This work shows how the bio-based product does not always represent the better way in term of environmental sustainability, especially nowadays where recycling processes have become an important topic.

1. Introduction

The use of plastic products is various and identifies several applications. Plastic represents the engineering material of our age, being used to substitute traditional materials like wood, glass and metal, in a variety of forms (Arena et al., 2003). The European consumption of plastic is equal to 51.2 million tonnes, which represents the largest global market for plastic resin consumption. The consumption of plastic packaging, which includes flexible films and rigid containers, accounts for 39.7% of the total European production. (PlasticsEurope, 2018). The production of plastics relies on crude oil. Therefore, the limited nature of this resource together with geopolitical constraints, cause fluctuations in its final price, thereby influencing the plastics market (Siracusa et al., 2008). These economic reasons and also environmental issues impose to search alternative raw materials in order to resolve the problems related to resources of fossil origin. The net

Paper Received: 7 April 2018; Revised: 7 October 2018; Accepted: 23 December 2018

Please cite this article as: Giovenzana V., Casson A., Beghi R., Tugnolo A., Grassi S., Alamprese C., Casiraghi E., Farris S., Fiorindo I., Guidetti R., 2019, Environmental Benefits: Traditional Vs Innovative Packaging for Olive Oil, Chemical Engineering Transactions, 75, 193-198 DOI:10.3303/CET1975033

amount of plastic at the global level arises from both the quantity of crude oil extracted and the final product waste management (Jambeck et al., 2015). Under this perspective, recycling of un-degradable products represents an established approach for a more efficient end of life of these materials (Kirwan & Strawbridge, 2003). Indeed, the recycling operations imply a lower environmental impact in terms, for example, of energetic resources (93% of crude oil, 84% of gas and 93% of coal), waste production (59%) and green-house gases emission (88%) (Arena et al., 2003).

The largest part of plastics currently used for food packaging applications is made of petroleum-derived materials. The non-renewable nature of these materials drives the search for new and renewable alternatives, in line with the increasing demand for disposable, potentially biodegradable, and recyclable solutions (Weber et al., 2002; Lopez-Rubio et al., 2004).

Bio-based plastics are currently the most promising solution to counterbalance the negative impact of non-renewable resources. Many studies have identified so far a number of bio-based polymers as potential candidates for food packaging applications. For example, Bogaert & Coszach (2000), Jamshidian et al. (2010) studied the properties and the processing possibilities of polylactic acid (PLA), which is a bio-based biodegradable thermoplastic polyester obtained from the conversion of corn into dextrose, followed by fermentation to obtain the biopolymer. Besides, the advantages arising from the renewable origin of the raw material, PLA offers to outperform benefits over the conventional plastics in terms of waste management due to its complete biodegradability. Bio-polyethylene (bio-PE), which was deeply investigated by Iwata (2015), Shen et al. (2010) and Babu et al. (2013), is synthesized from bio-ethanol, which in turn is obtained by the fermentation of glucose. Bio-PE has the same physicochemical and mechanical properties as petrochemical polyethylene (PE) (Shen et al., 2009). Under a waste management perspective, PLA and bio-PE behave in the opposite way. While both are bio-based polymers (thus obtained from renewable resources), PLA is biodegradable whereas bio-PE is not. Therefore, not only the origin of the raw materials must be considered, but also the waste disposal aspect (i.e., the final step of the life cycle) should be carefully taken into account for a proper selection of the packaging materials.

The aim of this study was to investigate the environmental performance of two different packaging solutions for extra virgin olive oil: i) conventional multilayer film made of polyethylene (PE), polyethylene terephthalate (PET) and aluminium foil; ii) innovative solution consisting of PLA and bio-PE. The single-dose sachet was considered as the worst-case scenario of the environmental impact of the packaging configuration for both materials. Life Cycle Assessment (LCA) (ISO 14040:2006) was used as a tool to identify the environmental profiles, to highlight the hotspots and make comparisons between these two packaging configurations.

2. Materials and methods

2.1 Functional unit and system boundaries

According to the ISO 14040:2006, the functional unit was defined as one mono-use packaging (10 mL volume). A cradle-to-grave approach was used. The study evaluated the environmental performance considering the activities from the raw material extraction, through the transformation and production phases, till the disposal of the used packaging. For both packaging, all activities with the same impact were not considered (e.g. the logistic phases).

2.2 Traditional packaging Life Cycle Inventory (LCI)

The traditional packaging was analysed, and optical measurements (spectroscopic and microscopic) allowed to identify five layers with different thickness: i) 15.29 μm 1st PE layer ii) 6.34 μm aluminium iii) 19.39 μm 2nd PE layer iv) 2.98 μm polyurethane (PU) v) 37.28 μm PET. The composition is presented in Table 1.

Table 1: Traditional packaging composition.

Material	Weight (g)	Percentage
PET	0.18	50.4%
PE (1st +2nd)	0.115	32.2%
Aluminium	0.062	17.3%
PU	0.0004	0.1%
Total	0.3574	100%

After the extraction of the raw materials, the PET and PE polymers are extruded to obtain the films while the aluminium foil is obtained by rolling procedures. The PE and PET films, the aluminium foil and the glue layer (PU) are laminated together using a lamination machine (productivity = 180 kg h^{-1}). After the lamination, the packaging film becomes the raw material for creating the final cylinder structure by filling and sealing the package with a forming machine (productivity = 80 unit min^{-1}). During the production phase, from the single film layer to the packaging film, an allocation procedure was performed to allocate to the functional unit the relative use of the machinery and the relative demanded energy. All the processes involved in packaging production are reported in Table 2.

Table 2: Machinery characteristics and energy requirements for the traditional packaging functional unit.

Process	Weight (kg)	Energy power (kW)	Weight / unit (kg)	Energy / unit (Wh)
Lamination	5’000	53	1.65e-8	0.103
Packaging	850	3.5	2.9e-6	0.730

A loss of product (assumed as 2.5%) is noticeable during the process, due to film trimming. When the trimming operation is performed on single layer film, the scraps could be addressed to recycling management, otherwise, it requires different waste management if it is performed on multilayer film.

2.3 Innovative packaging Life Cycle Inventory (LCI)

After spectroscopic and microscopic analyses, the composition of the innovative packaging was defined as: i) 26.55 μm of polylactic acid (1^{st} PLA layer), ii) 20.34 μm bio-PE and iii) 27.24 μm of polylactic acid (2^{nd} PLA layer), iv) a thin layer of aluminium sprayed between the two films. In table 3 the weights of the different materials setting up the innovative packaging are reported.
Along the innovative packaging production chain, the PLA film undergoes the physical vapour deposition (PVD) metallization phase. This process requires a machine that, vaporizing the aluminium under vacuum, deposits a small amount of aluminium on the film (Mattox, 2010). The under-vacuum metallization machine, as visible in Table 1 and 3, allows reducing the aluminium amount in the packaging. After the metallization, the two PLA films are laminated with the Bio-PE film using the lamination machine (productivity = 180 kg h^{-1}).

Table 3: Innovative packaging composition.

Material	Weight g	Percentage
PLA	0.24	76.6%
Bio-PE	0.067	21.4%
Aluminium	0.00614	2.0%
TOTAL	0.31314	100%

As the traditional packaging, also the innovative one is addressed to the packaging machine to obtain the final structure. The allocation of the machine weight and of the required energy was performed, and data related to one innovative packaging were calculated and reported in Table 4.

Table 4: Machinery characteristics and energy requirements for the innovative packaging functional unit.

Process	Weight (kg)	Energy power (kW)	Weight / unit (kg)	Energy / unit (Wh)
Metallization	55’000	227.2	4.8e-5	12.120
Lamination	5’000	53	1.44e-8	0.091
Packaging	850	3.5	2.9e-6	0.730

3. Results and discussion

3.1 Life Cycle Impact Assessment (LCIA): the production scenario

According to Chomkhamsri et al. (2011), ILCD 2011 method was applied considering the most significant impact categories: Climate Change (CC); Human Toxicity, Non-Cancer effects (HT-NC); Human Toxicity, Cancer effects (HT-C); Freshwater Ecotoxicity (FEco); Land Use (LU); Water resource Depletion (WD); Mineral, fossil & ren Resource Depletion (MRD). SimaPro 8.5 software has been used to elaborate the data for the impact assessment phase.
Figure 1 shows the production of traditional packaging. For all the impact categories, the production of raw materials, their transformation, the machinery used and the energy supply are highlighted. The main hotspot is the production of the aluminium film, which is ascribed mostly to the impact category mineral resource depletion (MRD, 93%). This incidence is due to the extraction, also called mineral cultivation, of the bauxite. This process damages the environment in terms of landscape and depletion of non-renewable resources as well as of human health (HT-NC 49%; HT-C 60%).

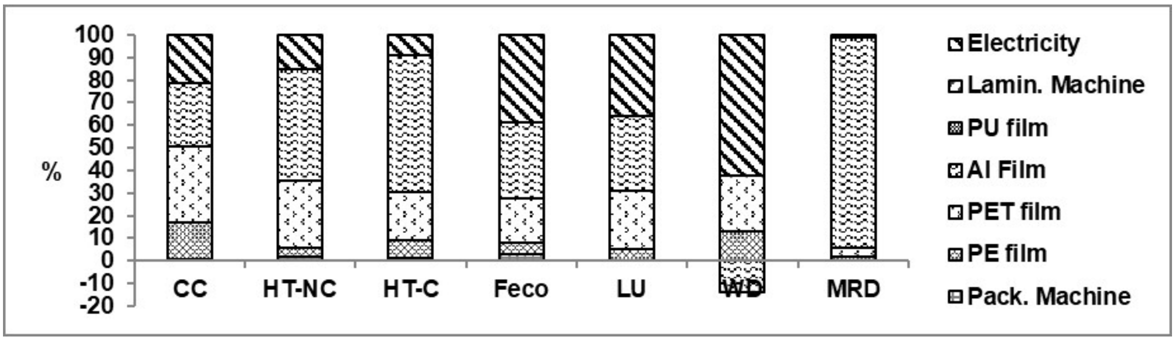

Figure 1: Percentage subdivision of the factors related to the production of the traditional packaging functional unit.

A positive aspect regarding bauxite extraction can be noticed and is ascribable to the WD (-17%). Although the bauxite extraction implies the use of a high quantity of water, the mineral extraction companies use recycled water or recycle the water to reduce water depletion, for this reason, the result is a negative impact. Another hotspot is the PET production chain, which incidence is related to all the impact categories with particularly high values for CC (34%). The incidence of this hotspot is mainly due to the raw materials extraction and to the transformation from polymers to films by chemical industries. The electricity required by the transformation machines is the third hotspot (from 8.8% HT-C to 62% WD). The high demand for electricity is due to the machines dimension and the type of processing, ending up in a high percentage of incidence in all the impact categories.
Even if for the traditional packaging the plastic fraction represents one of the main hotspots, the highest one is related to the aluminium fraction. Therefore, to solve this criticism, the quantity of aluminium in the packaging should be reduced. The use of the innovative technique of aluminium deposition by PVD metallization reduced greatly the amount of this substance (93% MRD traditional packaging; 49% MRD in innovative packaging).

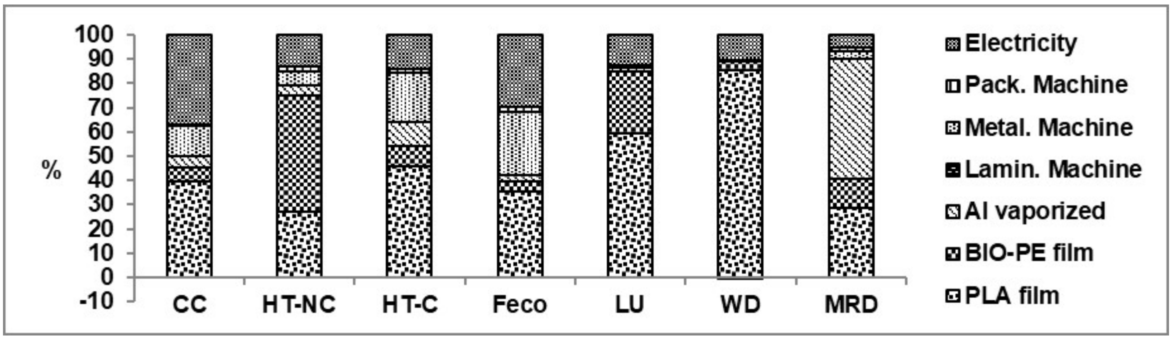

Figure 2: Percentage subdivision of the factors related to the production of the innovative packaging.

Figure 2 shows the impact production assessment of the innovative packaging. The main hotspot of the innovative packaging is the PLA film production. The high level of incidence of this material is explained by the composition of the innovative packaging, being PLA film more than 70% of the total weight. The incidence and high level of impact in all the impact categories are due to the process activities to obtain the bio-based polymer. The PLA needs a fermentation phase that requires a high quantity of water, thus reaching 85% of incidence in the impact category WD. Similarly, the bio-PE film is obtained by fermentation and requires chemical activities but its lower quantity in the packaging film justifies the less impact influence in all categories. A comparison of the two products in order to identify what packaging is better in each impact category (Figure 3) is needed. For some impact categories, the traditional packaging has the worst environmental profile. However, for the impact categories that are related to the ecosystem quality like LU and WD, the traditional packaging shows a better environmental profile.
It must be noted that in Figure 3 the results are characterized by different measure units and have a very different order of magnitude. A better environmental impact for the innovative packaging is not observed for all the impact categories. Regarding the CC, the innovative packaging production release 44% less of kg CO_2 eq (0.96 g) with respect to the traditional packaging (1.71 g). The same positive observation can be done for the impact category HT-C and MRD. In particular, the innovative packaging production process allows a reduction of MRD equal to 82% (from 1.14 mg to 0.21 mg of Sb).

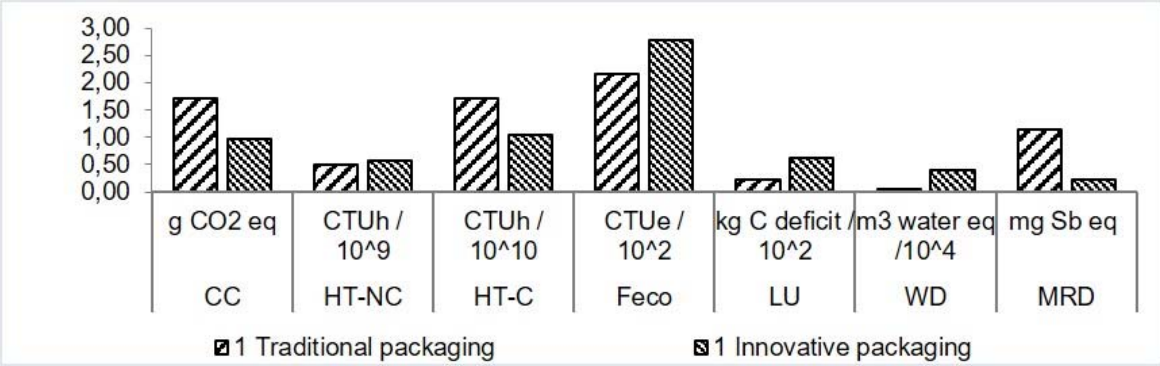

Figure 3: Comparison of the environmental profile of the two packaging materials for the most relevant impact categories.

Regarding the ecosystem quality, the two packaging solutions show reverse environmental impact; e.g. the impact categories related to the ecosystem quality, as Feco, LU and WD, present higher values for the innovative packaging than for the traditional packaging. The reason for this derangement is the fraction allocated to the cultivation phase of the renewable resources for bioplastic production. Even if for the bioplastic production by-products, from the cultivation and farming phases, are used, they still present a higher impact compared to the traditional plastic production.

3.2 Life Cycle Impact Assessment: the waste management scenario

The waste management scenario is complex because of a number of factors that must be considered: (i) the composition of the packaging, (ii) the properties of the single materials, (iii) the regional waste management procedures, (iv) the dirty packaging (olive oil inside) and (v) the consumers' behaviour.
Regarding the first two factors, both packaging systems are made from different materials, and the traditional one presents a higher quantity of aluminium, which could complicate the waste management. Regarding the innovative packaging, its composition showed less aluminium, but it has two different bio-based plastic materials, each of them presenting different characteristics of degradability, compostability and recyclability. Due to these considerations, the two packaging materials do not have clear disposal procedures, besides, different regional governments enforce differences in waste management. Nevertheless, taking into account the normal use of these packaging solutions, it should be considered that the product is consumed in restaurants, company canteens, schools, hospitals or outdoors. In these situations, the potential consumers, when deciding to dispose the packaging, easily will dispose it in the undifferentiated garbage.
These assumptions address studying incineration, which represents the worst case of waste management, but is the most common practice situation of meal consumption outside home. Considering that the two different packaging solutions are made of different materials, the analysis takes into consideration different incineration possibilities. The traditional packaging has been treated as a plastic material, while the innovative one as organic material. In Table 5 the results of the environmental impact from production to incineration phases are reported. Differences between traditional and innovative units are mainly ascribable to differences in composition.

Table 5: Comparison of the environmental profile of the two packaging materials regarding the most relevant impact categories from raw materials extraction to incinerator waste management.

Impact category	Unit of measure	Traditional packaging	Innovative packaging	Ratio level
CC	kg CO_2 eq	7.40e+08	7051.2	1.05e+05
HT-NC	CTUh	1.07e+07	5.96e+04	1.79e+02
HT-C	CTUh	1.37e+15	87662.5	1.56e+10
Feco	CTUe	8.09e+19	2.80e+13	2.89e+06
LU	kg C deficit	0.002	0.006	3.47e-01
WD	m3 water eq	5.71e-06	4.04e-05	1.41e-01
MRD	kg Sb eq	1.44e+09	188.5	7.62e+06

The innovative packaging, including the incinerator scenario, confirmed its more sustainable features. The higher ratio level between the traditional packaging and the innovative one is related to the impact category HT-C (1.56e+10). Moreover, weighting the obtained results, HT-C is the category with a higher magnitude.

4. Conclusions

A comparison of the environmental impact of two single-dose plastic packaging for olive oil (traditional and bio-based plastic) was performed in this study. Compared to the traditional packaging, the innovative one has a better profile, but not for all the impact categories. As for the ecosystem quality impact categories, the innovative packaging has the worst environmental performance (+78% Feco, +35% LU, +14.6% WD) due to the activities necessary along the production chain (cultivation of the maize, starch production, machines for farming activity, fermentation and chemical processes for polymers production). However, the innovative packaging is more environmentally sustainable than the traditional one considering the waste scenario, since the bio-based plastic, when incinerated, has a lower impact (CC ratio = 1.05e+05; HT-C ratio = 1.56e+10).
The overall assessment allows considering the innovative packaging a better solution from the environmental point of view. According to these results, further studies could be addressed to identify new packaging solutions, paying attention to the raw materials necessary for the production and to packaging composition in view of the recycling possibility of the multilayer film. The identification of low environmental impact bio-based packaging solution with 100% recyclability characteristics and high shelf life properties must be the goal for further studies.

Acknowledgements

This work has been supported by AGER 2 Project, grant n° 2016-0105, Sustainability of the Olive oil System (S.O.S.).

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