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Environmental assessment of antimicrobial coatings for packaged fresh milk

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ABSTRACT

Antimicrobial coatings are being increasingly used as a means to extend the shelf life of food products. This extension helps consumers cut down on the food waste generated at household level, while at the same time reducing the impact, which these products' life cycle has on the environment. The aim of this Life Cycle Assessment study is thus to assess the consequences on the environment arising from the application of an antimicrobial coating onto the packaging of a fresh milk product, while also taking into account the reduction in milk waste.

The antimicrobial coating considered is a synthetic derivative of lauric acid. The application of the coating involves additional environmental impacts caused by all the inputs and outputs which occur during its life cycle. At the same time, however, the use of this coating allows to extend the fresh milk's shelf life with a consequent reduction in food waste.

The data related to the production and application of the coating were provided by the packaging laboratory of the Institute of Agrochemistry and Food Technology (Valencia) and by manufacturing companies. The data related to food waste, milk processing, refrigeration transports, storage, and end of life of both product and packaging were obtained from previous studies, institutional reports and Ecoinvent database v2.2. The Midpoint Impact 2002 method was used to assess impacts.

The results show how the reduction in milk waste achievable by using the coating generates higher environmental benefits than the impacts caused by the coating's life cycle due to milk saving. Furthermore this study demonstrates the importance of including food waste in Life Cycle Assessment studies of packaging systems. The connection between packaging design and food waste is a decisive aspect in the evaluation of actual environmental sustainability and should thus be considered in all assessments of packaging solutions.

1. Introduction

About one-third of the food produced for human consumption is either lost or wasted, and this figure amounts to about 1.3 billion tons per year (FAO, 2011). On the one hand, this represents a serious issue from a social and ethical point of view, since the number of chronically undernourished people in the world remains unacceptably high (FAO, 2014). On the other, it also involves consequences on the environment since the manufacture of products which are subsequently disposed of both requires resources and causes emissions into air, water and soil in the phases of production and supply chain. This is confirmed by the global Carbon Footprint generated by food waste, which has been estimated as equivalent to 3.3 Gtonnes of CO_2 (FAO, 2013).

Reducing the amount of food waste is important for all food categories, and in particular for food products having high environmental impacts such as fish, meat and dairy products (Verghese et al., 2013). Most of the food waste can be avoided by acting, first of all, on the products' shelf life, since most of it is caused by food not being used before its expiry date, and this occurs particularly in the case of perishable products (WRAP, 2008). Fresh milk is one of the most highly consumed perishable products, and its shelf life is

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generally no longer than 7–9 days (Rysstad and Kolstad, 2006). Moreover, once the package has been opened, the product is to be consumed within 2 days. For these reasons, milk waste is generally high in the phases of both supply chain and final consumption (FAO, 2011; WRAP, 2013).

The production and packaging processes play a central role in determining a product's shelf life. In the specific case of fresh milk, the technological optimization of the manufacturing process could extend the product's shelf life (Rysstad and Kolstad, 2006; Craven et al., 2008), but it cannot increase the number of days available for consumption once the package has been opened, as this indeed involves microbial contamination of the product which cannot be contrasted by the manufacturing process or the type of packaging materials.

The most novel alternative for extending the life of the product after opening is associated with the use of active packaging, in particular antimicrobial packaging (Mastromatteo et al., 2010). This is a technology which inhibits or retards the proliferation of microorganisms in foods which is a consequence of food/packaging interactions (Appendini and Hotchkiss, 2002). The incorporation of an antimicrobial agent into a packaging film able to release it through the coating surface into the food in a controlled way provides a continuous antimicrobial effect on the food during the product's shelf life (Muriel-Galet et al., 2014). A coating based on an ethylene-vinyl alcohol (EVOH) copolymer having LAE (lauramide arginine ethyl ester) as antimicrobial compound has recently been developed (Muriel-Galet et al., 2012). The preparation and application of LAE are described in several patents and papers (Urgell Beltran and Seguer Bonaventura, 2003; Rodriguez, 2004); it is one of the most powerful food antimicrobial agents, with a broad spectrum of antimicrobial activity. This coating can be applied to packaging film by using a gravure printing technique and its addition to a packaging structure significantly extends the shelf-life of liquid products such as fresh milk, as further described below, thus reducing food waste, although the introduction of this additional step to the normal packaging production phase involves a source of additional environmental impacts. In order to assess the actual environmental sustainability of this innovative technology, these impacts need to be compared with the environmental benefits brought by the reduction in food waste.

The adoption of scientific reliable tools is essential to assess the real environmental sustainability of a product or a system. Life Cycle Assessment (LCA) is a standardised method (ISO, 2006a, b) which assesses potential environmental impacts associated with a product, process, or service throughout its life cycle, and is internationally recognised as the best tool to evaluate the environmental performance of products or systems (EC, 2003, EC, 2013a,b; EC, 2008). In recent years this method has been widely used to investigate the sustainability of the manufacture and packaging of food products (Meneses et al., 2012; Manfredi and Vignali, 2014). These studies have generally been carried out by considering one unit of purchased or delivered food product as a functional unit, i.e. as the reference unit of the analysis. In other cases, comparative analyses of packaging solutions have been performed without considering the environmental impact of food production, mainly by taking into account the impact of packaging materials (Kang et al., 2013; Papong et al., 2014) or adding the packaging processing (Toniolo et al., 2013; Cleary, 2013; Manfredi and Vignali, 2015). Both these approaches can be misleading, especially for comparative analysis between different packaging solutions in which the packaging properties could affect the amount of waste throughout the supply chain. In fact, in some cases changes to the packaging material which may lengthen the shelf life have a greater environmental impact. However, the modified material is able to reduce food waste as the food lasts longer (Williams and Wikström, 2011). The connection between packaging design and food waste should therefore be acknowledged and included in the analysis, as packaging designed as environmentally friendly but ineffective in protecting food may otherwise appear to be a better environmental alternative than packaging which helps reduce food losses (Williams et al., 2012).

Wikström et al. (2014) have recently demonstrated via six packaging scenarios how the inclusion of the function “avoiding food waste” in an LCA study is necessary to evaluate the real sustainability of a packaging system. Moreover, Silvenius et al. (2014) evaluated the environmental impacts resulting from food waste generated by consumers as a function of the packaging properties, revealing that packaging solutions which minimize food waste generation lead to the lowest environmental impacts of the entire product-packaging chain. No LCA study has so far been performed on packaging systems with an active antimicrobial coating, which however it would be important to assess if the reduction in food losses increased the environmental sustainability of the entire milk-packaging system.

The main purpose of this paper is to show the influence of the package on the amount of food waste by comparing the environmental profile of a traditional packaging system with the profile of a packaging coated with an active layer for fresh milk packaged in Tetra Top® beverage containers. This comparison is performed by applying LCA method to both types of packaging. The study also includes a sensitivity analysis in order to understand how the variation in food waste might affect the total environmental sustainability of a packaging system.

The remainder of the article is organized as follows: Section 2 contains a description of the coating production and application as well as an estimate of the milk waste reduction from applying the coating; Section 3 reports the characteristics of the LCA study, while the main results of the analysis and a further sensitivity analysis are explained in Section 4; a Conclusions section summarizes the main results, highlights the limitations of the study and makes some suggestions for future research.

2. Description of the system analysed

The aim of the present study is to assess the environmental performance of a specific antimicrobial coating applied to fresh milk Tetra Top® packaging by using the LCA method. This coating is able to extend the product's shelf life, thereby reducing the amount of product waste. The production of fresh milk is a standardized process whose phases are well explained in literature (Fantin et al., 2012). The data about the milk processing and packaging used as a starting point for our analysis have been taken from the study by Fantin et al. (2012).

The properties of the antimicrobial coating added to the traditional system and the evaluation of the potential benefits in terms of reduced waste in the consumption phase are explained in this section.

2.1. LAE coating

LAE (ethyl-Nα-dodecanoyl-L-arginate hydrochloride), a synthetic derivative of lauric acid, L-arginine and ethanol (Higueras et al., 2013; Muriel-Galet et al., 2012, 2014), is one of the most innovative antimicrobial agents and is noted for its antimicrobial effectiveness, which derives from its chemical structure and surfactant properties. Its antimicrobial properties are due to its action as cationic surfactant on the cytoplasmic membrane and the outer membrane of Gram-negative, and the cell membrane and cytoplasm of Gram-positive denaturation proteins. These changes