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Shelf Life Extension to Reduce Food Losses: the Case of Mozzarella Cheese

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Agro-food is considered one of most polluting economic sector, in particular due to the large amount of greenhouse gases (GHGs) emission, the contribute to the terrestrial acidification, the depletion of water resources and the large amount of wastes linked to agricultural production, end of life of food products and food losses. Among agro-food systems, livestock sector represents the worse performance, producing, for example, about 60 % of GHG emissions. Dairy production amplifies this phenomenon, requiring a large amount of input materials to produce little quantity of products and generating, along the supply chain, a great quantity of wastes.
The aim of this study is to evaluate, from an environmental and economic point of view, the introduction of an innovative shelf life extension (SLE) technique and its effects in terms of reduction of wastes and food losses in the Lacto Fermented Mozzarella Cheese production. A new liquid formulation containing antimicrobials, that extends the shelf-life of mozzarella, was tested as governing liquid to contrast the product degradation due to the bacterium *Pseudomonas syringae*. The use of calcium lactate and bergamot extract in freshwater solution, allowed an extension of shelf life close to 50 %.
Life Cycle Assessment and Life Cycle Costing methodologies were applied to evaluate the effects of SLE implementation, taking also into account the potential reduction of food loss and returned goods.
Results showed that despite a minimal increase of impacts and costs due to the introduction of the innovation, the SLE could allow reducing the share of losses up to 50%. Expressing results in terms of days of product shelf life, the innovative solution is more sustainable from both the environmental and the economic point of view. Insights can be used for the eco-design of high quality products.

1. Introduction

Food represents the principal requirement for every organisms, in particular for humans, who, in function of food resources, shaped the geographical conformation of the planet and influenced the history of humanity (Kiple and Ornelas, 2000; Diamond, 2002).
The incessant challenge for food production, allowed the rich countries to respond to food requirement of people, also providing an answer to other emerging needs linked to the food, for example cultural or aesthetic ones (Notarnicola et al., 2017). The inexorable race to produce more and better food generated the rebound effect of food losses, producing, according to FAO estimation, 1.3 billions of edible food wastes (Gustavsson et al., 2011; Corrado et al., 2017). According to Garrone et al. (2016), food production, represents today an environmental cost, boosting scientific community and food companies searching innovative solutions to reduce environmental impacts and wastes.
In this scenario, the development of Life Cycle Thinking and of methodologies inspired to it (Life Cycle Assessment - LCA, Life Cycle Costing - LCC and Social Life Cycle Assessment – sLCA) gained increasing consensus as appropriate tools for the evaluation of environmental, economic and social burdens (De Luca et al., 2015a, 2015b, 2015c; Iofrida et al., 2016). Several papers were published in the agro-food sector, specially thanks to the boost given by International Conferences on LCA of Food (Schenck and Huizenga, 2014; LCA Food Conference Committee, 2016). Different supply chains have been object of study, for example, the agricultural sector (Gresta et al., 2014) the beverage industry (De Marco et al., 2016a), the food

processing (De Marco et al., 2016b) and the bioenergy production (Beaver et al., 2016). Life cycle methodologies have been applied as stand-alone tools (e.g. Stillitano et al., 2016) or jointly in order to assess the integrated sustainability (De Luca et al., 2015b and 2015c).
Livestock production represents one of most investigated theme (McAuliffe et al., 2016; Baldini et al., 2017) due to its environmental relevance.
According to FAOSTAT (2017), over 65 % of global agricultural emissions of CO_2 equivalent were produced by livestock and connected activities. Farm animals are also a great exploiter of resources. For example, in terms of water, the animal production shares about 29 % of global agricultural water footprint (Mekonnen and Hoekstra, 2012). Dairy industry produces a multiplier effect of impacts, using a large amount of primary products to make little quantity of cheese (approximatively 10 litres of milk for 1 kg of cheese) and then, each unit of product loss carries with it several impacts.
The aim of this study was to evaluate, from an environmental and economic point of view, a new technique for the shelf life extension (SLE) of Lacto Fermented Mozzarella Cheese. Results showed that the new SLE technique could contribute to the reduction of product loss and then to the improvement of environmental and economic sustainability.

2. Methodological implementation to the case study

The Lacto-fermented mozzarella cheeses were manufactured from cow's milk in a firm located in Reggio Calabria, southern Italy. About four mozzarella cheeses (weighting 125 g each) were then packaged in polypropylene trays with tap water (control) and an alternative governing liquid consisting of 0.2 % calcium lactate + bergamot extract solution (CL-B). The samples were stored at 5 °C and several microbiological and chemical-physical indexes were monitored to 18 days. All the analyses were conducted in triplicate and statistically analysed by ANOVA one-way using SPSS Statistics 17.0 software.
After the technological check of CL-B, an environmental and economic evaluation was performed in order to define the effectiveness of innovative solution. The environmental analysis was made through the LCA methodology (ISO, 2006a and 2006b) by evaluating as Functional Unit (FU) both 1 kg of packaged product and 1 day of shelf life, in order to assess the effects of SLE on environmental profile. The study was extended from cradle to grave in order to include in the system boundaries also the unsold products (Figure 1).

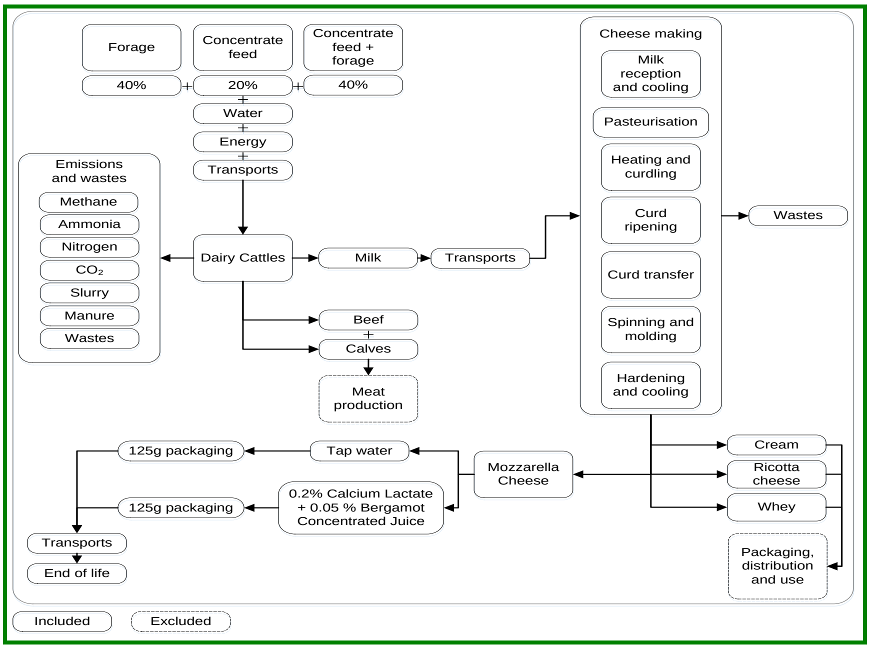

Figure 1: System boundary flow chart

Primary data were directly collected from three different dairy farms which confer the milk to the cheese factory where the experimentation was made. Data on animal feeds composition were directly collected as well as data on feed production, water and energy consumption and waste production and treatment. Data on methane, ammonia, nitrogen and carbon dioxide emissions were taken from Agri-footprint (Blonk Agri-footprint BV, 2015) and Ecoinvent V3.3 (Frischknecht et al., 2007) database. Data on energy use in the cheese factory

were measured through Fluke 179 True RMS Digital Multimeter instruments; data on water use were measured through a Water Flow Meter and data on methane gas used for heating were measured through the Flow Meter installed to the plant. Transports distances were measured, and classified according to the typology of means of transport. Data on distance travelled by final consumers were estimated. Waste water treatment was included using the waste scenario included in Ecoinvent 3.3 and all the packaging was considered as waste disposed to the municipal landfill (both consumed and unsold ones). Both dairy farms and cheese factory input and output were allocated in function of economic value of products (Thomassen et al., 2008). Data were processed through the ReCiPe midpoint impact method (Goedkoop et al., 2013).
The same criteria were used for Life Cycle Cost evaluation, by adding to the monetized values of inputs and outputs, the cost of wages, the quotas and other duties, interests, land capital use and externalized services (Falcone et al., 2015, 2016). The computational framework proposed by Ciroth and Franze (2009) and by Moreau and Weidema (2015) was used, borrowing the same computational framework of LCA. Considering the same selling price both for control and innovative products, the adding value originated by different production processes was determined. Also for economic evaluations, two FUs were used in order to define the effects of SLE. In particular, the cost was determined per day of SL, also considering the costs for unsold returned goods, as lost value (Buzby et al., 2014).

3. Results and discussion

In Table 1 some significant qualitative parameters measured in Mozzarella cheeses are reported. Compared to the initial time of storage, the Mozzarella cheeses underwent several expected variations during the time, as a decrease of pH, NaCl %, the hardness parameter and an increase of the Total Microbial Count. The shelf life of the control Mozzarella sample was attested to 12 days. The CL-B sample manifested a longer shelf life (18 days) than the control sample that did not appear instead acceptable from both the sensorial and microbiological points of view.

*Table 1: Qualitative parameters of Mozzarella samples. ** Significance at P<0.01*

Storage time	12	18	Sign.
Sample	Control	CL-B	
pH	5,98±0,02	5,56±0,01	**
NACl (%)	3,41±0,10	0,92±0,10	**
Hardness (N)	9271,54±2,14	4741,87±59,70	**
TMC (log CFU/g)	3,08±0,74	6,63±0,01	**

The improvement of the mozzarella shelf life corresponds, from an environmental point of view, to a minimal increase of impacts in all categories. However, this increase did not exceed the 1 % (see the ratio CONT./CL-B), except for Ozone depletion and Photochemical oxidant formation, where the increase of impacts get close to 3 %. Analysing the findings from another perspective, using 1 day of shelf life as FU, the CL-B mozzarella resulted to be better than Control, with a ratio that overtake the 30 % (Table 2).Confirming other studies (e.g. González-García et al., 2013) milk production represents the most important hotspot, contributing for each impact category at least the 50 % of environmental loads, in particular for Water depletion, Agricultural land occupation and Natural land transformation. Impact of milk production can vary effectively, as verified also by the findings of Fantin et al. (2012). Ozone depletion, Urban land occupation and Fossil depletion are highly influenced by transports, nevertheless, significant are the impacts of cheese-making processes due to the high energy requirement. Insights by Palmieri et al. (2017) showed that transports have lower impacts ratio, however, as specified by authors, this can be attributable to the short distance from dairy farms to the processing plant.
From the economic point of view, results showed a more complex scenario. Costs were equal for both products, except for the packaging, as the innovative solution is obviously more expensive (Figure 2). However, accounting as a cost the unsold product, the control scenario overtook of 2.5 % the innovative solution, because the SLE reduced the amount of returned goods (Figure 2). In this context, considering the same selling price for both solutions, the CL-B mozzarella had a higher value added (Control, 0.51 € kg^{-1}; CL-B, 0.65 € kg^{-1}). In term of costs, the gap between Control and CL-B was in favour of CL-B solution, while considering as FU “1 day of shelf life”, the CL-B resulted a 36.7 % better. Also from the economic point of view, milk represented the biggest hotspot, followed by wages and packaging, confirming results obtained by Durham et al. (2015). Likewise, quotas had a higher economic impact as well as electricity and other energy sources.

Table 2: Life Cycle Impact Assessment (LCIA) results

Impact category	Unit	1 kg of product CONTROL	CL-B	CONT./ CL-B	1 day of shelf life CONTROL	CL-B	CONT./ CL-B
Climate change	kg CO_2 eq	9.6E+00	9.6E+00	99.7%	8.0E-01	6.0E-01	132.9%
Ozone depletion	kg CFC-11 eq	5.5E-07	5.6E-07	98.3%	4.6E-08	3.5E-08	131.1%
Terrestrial acidification	kg SO_2 eq	1.2E-01	1.2E-01	99.7%	9.7E-03	7.3E-03	133.0%
Freshwater eutrophication	kg P eq	1.1E-03	1.1E-03	99.7%	9.5E-05	7.1E-05	132.9%
Marine eutrophication	kg N eq	2.5E-02	2.5E-02	99.9%	2.1E-03	1.6E-03	133.2%
Human toxicity	kg 1,4-DB eq	8.5E-01	8.5E-01	99.4%	7.1E-02	5.3E-02	132.6%
Photochemical oxidant formation	kg NMVOC	1.5E-02	1.6E-02	97.1%	1.3E-03	1.0E-03	129.4%
Particulate matter formation	kg PM10 eq	2.0E-02	2.0E-02	99.2%	1.7E-03	1.3E-03	132.3%
Terrestrial ecotoxicity	kg 1,4-DB eq	2.3E-02	2.3E-02	100.0%	1.9E-03	1.4E-03	133.3%
Freshwater ecotoxicity	kg 1,4-DB eq	4.5E-02	4.5E-02	99.6%	3.7E-03	2.8E-03	132.8%
Marine ecotoxicity	kg 1,4-DB eq	3.8E-02	3.8E-02	99.5%	3.2E-03	2.4E-03	132.7%
Ionising radiation	kBq U235 eq	3.6E-01	3.6E-01	99.4%	3.0E-02	2.2E-02	132.5%
Agricultural land occupation	m^2a	4.4E+00	4.4E+00	100.0%	3.7E-01	2.8E-01	133.3%
Urban land occupation	m^2a	7.5E-02	7.5E-02	99.9%	6.2E-03	4.7E-03	133.1%
Natural land transformation	m^2	1.1E-02	1.1E-02	99.9%	9.4E-04	7.0E-04	133.2%
Water depletion	m^3	2.8E-01	2.8E-01	99.9%	2.3E-02	1.7E-02	133.1%
Metal depletion	kg Fe eq	1.6E-01	1.6E-01	99.2%	1.4E-02	1.0E-02	132.3%
Fossil depletion	kg oil eq	1.4E+00	1.4E+00	99.2%	1.2E-01	9.0E-02	132.3%

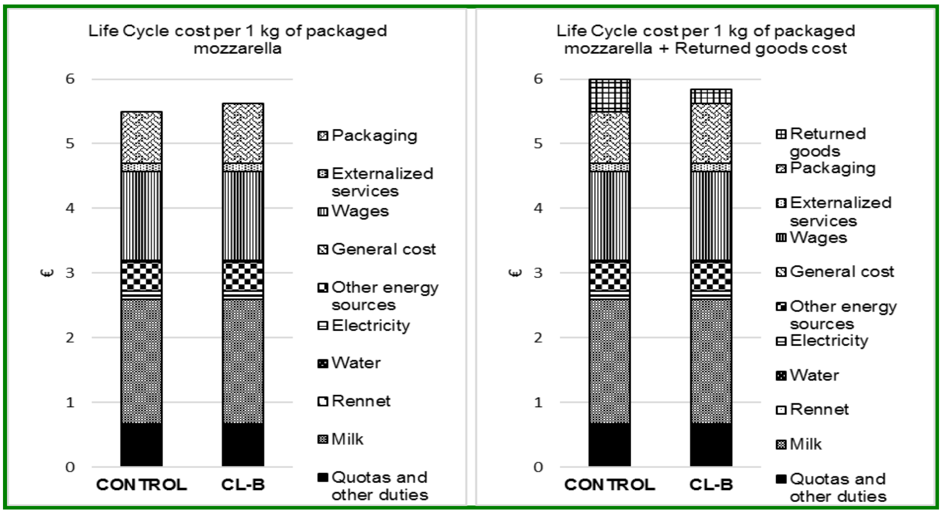

Figure 2: Results of the economic analysis

If the application of the 0.2 % calcium lactate + bergamot extract solution (CL-B) obviously contributed to the costs increasing, the decrease of economic performances was less than proportional with SLE. In this sense, we hypothesize that the extension of 50 % of SL could correspond to a reduction of 50 % of unsold product. Furthermore, considering that, from direct surveys, the total amount of unsold products represents on average the 9 %, the extension of six days of the Shelf Life could be sufficient to have “zero returns”, and then, probably, to contribute to reduce the food loss and waste.

4. Conclusions

The aim of this study was to evaluate, both from environmental and economic perspective, an innovative government liquid for lacto-fermented mozzarella cheese, in order to extend the shelf life and to reduce the food losses. Through LCA and LCC methodologies, the innovative solution, based on a mix of 0.2 % calcium lactate + bergamot extract, was compared to the Control one in order to evaluate the effectiveness of innovation. Results showed an extension of 50 % of the shelf life, maintaining the organoleptic characteristics, almost without environmental consequences. Considering the effects of SLE, the food losses are reduced and, consequently, the derived costs. Results were useful to highlight the main hotspots in mozzarella cheese production and to suggest improvements for a more sustainable management. Future studies would experiment more government liquids at different concentrations, in order to identify other viable solutions to improve the SL of mozzarella cheese and furtherly reduce food losses.

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