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Economic and Environmental Assessment of Extra Virgin Olive Oil Processing Innovations

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Italian olive-oil industry records a loss in competitiveness in the world market, mainly because of low technological innovation level of companies that prevents them from obtaining high-added value products. In this scenario, a more efficient farming management and the adoption of product and process innovations may help to increase the quality of olive oil production, in order to meet the consumer's needs and, therefore, moving towards a more competitive market. The present study aims at evaluating, from an economic and environmental point of view, the introduction of a physical co-adjuvant (calcium carbonate) during extra virgin olive oil (EVOO) extraction and its effects on oil yield and quality, and on plant energy consumption. Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) were used respectively for economic and environmental analyses, by implementing a common methodological framework useful to achieve joint results. Preliminary findings showed that the addition of calcium carbonate during the malaxing operation allows reducing the operational time and then the environmental impacts and costs. Further progress of research could explain if there are also significant variations in the oil yield, leading to potential advances in EVOO production.

1. Introduction

Olive oil production represents an essential asset for the European Union (EU) countries bordering the Mediterranean sea, producing about 75% of the world's olive oil (Faostat, 2018) with a positive trend (+ 6 %) since 2004 to 2014. Spain is the largest producer, followed by Italy and Greece. However, the increasing tendency in these countries is not uniform in the analysed decade. Indeed, in 2004 the percentage of olive oil produced in Spain, Italy and Greece corresponded, respectively, to 46 %, 36 % and 14 % of the total EU production, while in 2014, Spain increased his share to 75 % and, to the contrary, Italy dropped to 12.7 % and Greece to 9 % (Faostat, 2018).

The loss in competitiveness of Italian olive-oil sector could be attributed both to the recent and widespread phytosanitary problems, e.g. the quick decline syndrome of olive (Almeida, 2016), but also to an inadequate technological level of farms and especially of mills. If the modernisation of olive grove appears in progress in the main Italian olive-growing areas, this is not completely verified for the innovation of industrial plants due to the high costs of machinery and the limited share of their utilisation that entails a long depreciation period for these facilities. Another limiting factor could be represented by the regulation of olive oil production that, properly, bans any chemical extraction process for Extra Virgin Olive Oil (EVOO) and thus, making it impossible to acquire lower-cost extraction systems.

In this context, new technologies' investments or marginal improvement of current plants performances could represent, most likely, the only way to innovate the EVOO industrial process. In this sense, several studies (Squeo et al., 2016; Caponio et al., 2018) have shown the effectiveness of the addition of calcium carbonate during the malaxation process.

This study aims to evaluate, from an environmental and economic point of view, the effect of the addition of $CaCO_3$ during the malaxation process. Results showed that the modification of rheological properties of olive

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paste allows obtaining better economic and environmental performances in comparison with traditional extraction system, above all in terms of efficiency of machinery use and shorter processing times.

2. Methodological implementation to the case study

A homogeneous lot of Coratina cv. olives (*Olea europaea* L.) was used for the experimental study. The olive oil mill was equipped with a continuous olive oil extraction plant with a theoretical work capability of 2500 kg h^{-1}, made up of a hummer crusher Vitone FR 30 (Vitone s.r.l., Bitonto, Italy) with a work capability of 3000 kg h^{-1}, followed by six parallel malaxer machines Barracane 9KPLC (Barracane s.r.l., Modugno, Italy). The plant was completed by a three-phase decanter Vitone V3 (Vitone s.r.l., Bitonto, Italy) with a work capability of 2500 kg h^{-1}, operating at 3200 rpm, and a liquid/liquid vertical plate centrifuge Barracane Grande 3000 (Barracane s.r.l., Modugno, Italy) with a work capability of 800 l h^{-1}, operating at 6500 rpm. During the experiment, only one malaxer was used.

To study the effect of the technological innovation, calcium carbonate (Omya S.p.a., Milan, Italy) having an average particle size of 5.7 μm (Calcipur®5) was used at 2 % by weight respect to the olive mass.

Two theses were set up using 600 kg of olives from the same lot per each. Olives were processed within 6 hours from harvesting. The control (C), followed the common extraction process. In particular, exactly 300 kg of olives were weighted, crushed through the hammer crusher, and the resulting olive pastes sent to the malaxer machine. The malaxation step conditions were 40 minutes at 26±1 °C. After 40 minutes the olive pastes were sent to the 3-phase decanter, set with a mass flow rate of 1900±20 kg h^{-1} and, after this stage, the oil was finished through the vertical centrifuge. About 30 % of water was added to the decanter. In the innovative process, the malaxation time was reduced to 20 minutes, with an addition of about 20 % of water and of 2 % of the coadjuvant. Then the olives paste was sent to the 3-phase decanter working at 2500±20 kg h^{-1} as mass flow rate.

Two different extractions were carried out for each trial and two oil samples per each were collected and immediately packaged in dark glass bottles until the analyses.

The extraction yield (EY) was calculated as the percentage ratio between the olive oil mass obtained (W_oil) with respect to the olive mass worked (W_olive) expressed in kg.

For the technological experiment conducted, the environmental profile of was carried out by means of Life Cycle Assessment (LCA) methodology (ISO, 2006a and 2006b) by considering as Functional Unit (FU) 1 bottle containing 0.75 l of EVOO. The system boundaries chosen were “from cradle to the milling plant gate” by excluding the distribution, the selling and the use phase (Figure 1). Data on foreground processes for olives production were directly collected from a sample of three ordinary farms from the Ionic side of Northern Calabria, characterized by the cultivation of cv. Coratina. Data gathering was performed through a custom-made questionnaire, built in order to collect both environmental and economic input and output, to realize an all-inclusive environmental and economic Life Cycle Inventory (LCI). The average data of two-year production (i.e. 2016-2017) were collected and mean values were considered in order to reduce the effects of seasonality and farms management on data quality, as well as to attenuate the fluctuations of production yield which characterize the olive groves. Data of background processes, as fertilisers, pesticides, machinery and energy production, were taken from secondary sources (Eco-invent V. 3.4 and Agri-footprint V. 3 databases). Data on nitrous oxide and ammonia emissions were estimated according to Ecoinvent (2007); nitrate emissions were estimated according to Brentrup et al. (2000); pesticides emissions were estimated according to Margni et al. (2002) results.

Active, reactive and apparent power measurements were carried out by means of a Power quality meter & Analyzer CW 121 (Yokogawa Electric Corporation, Tokyo, Japan) and used to calculate the electricity consumption during processing. Data on operation times, oil yield, the quantity of co-products and wastes were directly measured through specific surveys.

Background data related to electricity production and wastes management were taken from secondary sources (Eco-invent V.3.4 and Agri-footprint V.3 databases), while data on co-products utilization were taken from Strano et al. (2014). Due to the lack of the data on the construction of milling plant machinery, these were excluded from the analysis. The economic allocation was applied to the main products of the extraction process, i.e. between EVOO and pomace.

Environmental inventory data were processed using SimaPro 8.4 software and, as Life Cycle Impact Assessment (LCIA) method, the ReCiPe 2016 (Huijbregts et al., 2017) was chosen to elaborate results from each scenario analysed.

To evaluate the affordability of scenarios analysed the same criteria were used to conducting a Life Cycle Cost (LCC) analysis, 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., 2017, 2015). LCC methodological approach of Ciroth and Franze (2009) and Moreau and Weidema (2015) was used, borrowing the same computational framework of LCA. Considering the same selling price both for Control and w/Calcipur®5 product, the adding value originated by different production processes was determined. The revenues were evaluated by including public subsidies (Stillitano et al., 2016, 2017).

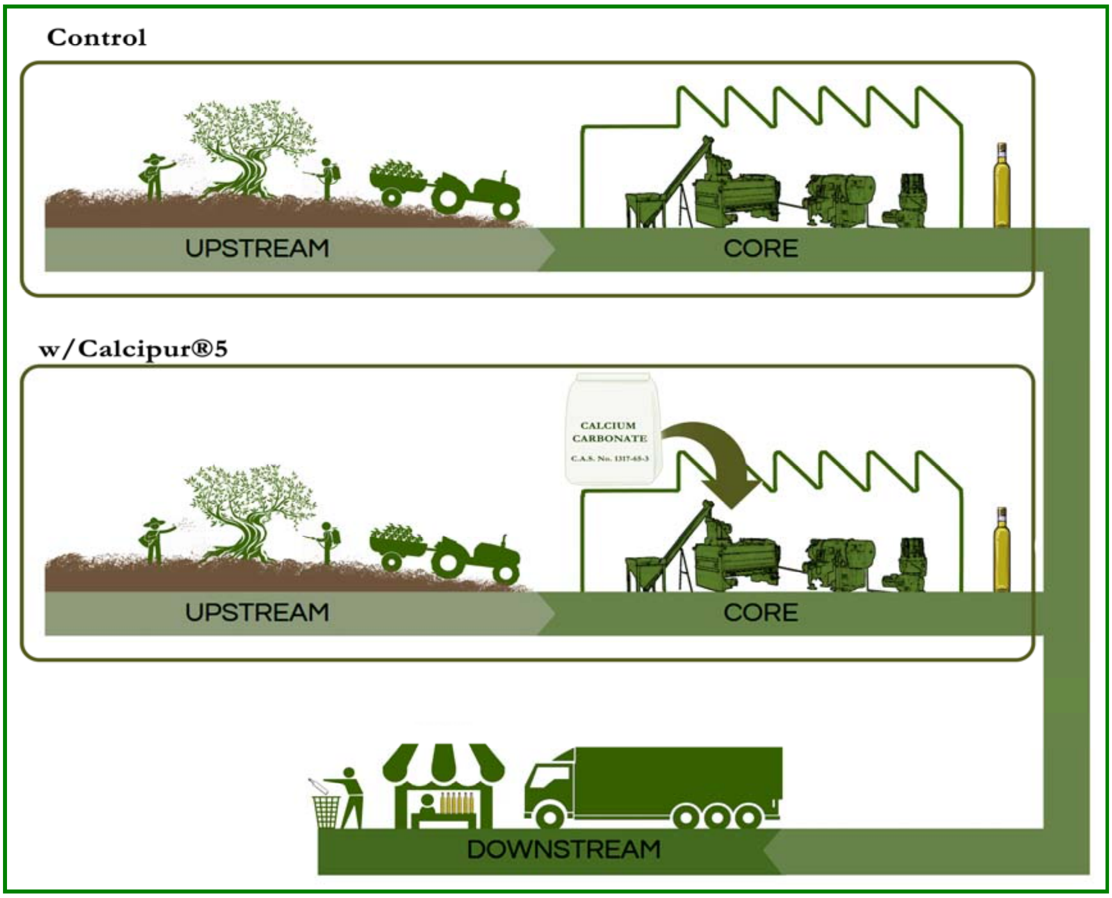

Figure 1: System boundary flow chart

3. Results and discussion

Table 1 reports the oil extraction yields for the experimental trials. No statistical differences have been highlighted between the common process and the innovative extraction in terms of extraction yield. However, the use of calcium carbonate gave notable result by a practical point. In fact, the use of the coadjuvant allowed to halve the malaxation step duration, while the total time of extraction was reduced to around 49.5 minutes, achieving around 33.5 % of reduction of process duration. Then, in our experimental plan, the main advantage of the use of calcium carbonate consists in the reduction of the malaxation time and therefore increasing the work capacity of the plant. For what concern the virgin olive oil (VOO) quality, all the samples belonged to the class of extra virgin olive oil (Reg. ECC 2568/91). Overall, the coadjuvant exerted a slight influence on the quality parameters, in some cases statistically significant. Indeed, due to the innovative process, a significant reduction of the free fatty acids (FFA) and peroxide value has been highlighted. Moreover, we observed a significant reduction in the total phenolic content (TPC) and, as a consequence, in the antioxidant activity. Such behaviour, confirmed by other studies (Squeo et al., 2016; Caponio et al., 2018) is currently under study. The extinction coefficients (K232 and K270), tocopherols and carotenoids content did not show any statistical difference with respect to the control process.

The environmental analyses showed that considering only the extraction process, the experimental scenario is more performing for almost all impact categories with the exception of “Mineral resource scarcity” category due to the use of calcium carbonate. The improvement of the environmental profile is mainly due to the optimization of operational times, which allows reducing the energy consumption for the olive oil extraction (Bacenetti et al., 2018). By considering the whole life cycle, including the agricultural production assessment, it can be noted a tendency to flatten out the results because of the higher incidence of upstream phase on environmental profile of olive oil (Bernardi et al., 2018; De Luca et al., 2018). For the only core process, the improvement is on average around 10 % while, if also the upstream process is considered, this advantage falls below 1 % (Table 2). In this sense, an increase of extraction yield could improve considerably the impacts of oil, by reducing the quantity of olive required to produce the functional unit considered (0.75 l of EVOO).

Table 1. Extraction yield

Trial	EY %	Mean	SD
Control	16.5	16.9	0.6
Control	17.3		
w/Calcipur®5	16.4	16.9	0.7
w/Calcipur®5	17.4		

Table 2. Life Cycle Impact Assessment (LCIA) results

		Extraction process		Olive oil	
Impact category	Unit	Control	w/Calcipur®5	Control	w/Calcipur®5
Global warming	kg CO_2 eq	1.78E-01	1.58E-01	5.13E+00	5.11E+00
Stratospheric ozone depletion	kg CFC11 eq	8.40E-08	7.47E-08	8.59E-05	8.58E-05
Ionizing radiation	kBq Co-60 eq	3.18E-03	2.85E-03	2.66E-01	2.66E-01
Ozone formation, Human health	kg NOx eq	3.63E-04	3.22E-04	1.39E-02	1.38E-02
Fine particulate matter formation	kg PM2.5 eq	2.16E-04	1.92E-04	8.59E-03	8.57E-03
Ozone formation, Terrestrial ecosystems	kg NOx eq	3.69E-04	3.28E-04	1.41E-02	1.40E-02
Terrestrial acidification	kg SO_2 eq	6.59E-04	5.87E-04	2.45E-02	2.44E-02
Freshwater eutrophication	kg P eq	3.70E-05	3.33E-05	2.15E-03	2.15E-03
Marine eutrophication	kg N eq	8.90E-06	8.41E-06	1.88E-04	1.88E-04
Terrestrial ecotoxicity	kg 1,4-DCB	2.41E-01	2.22E-01	2.76E+01	2.76E+01
Freshwater ecotoxicity	kg 1,4-DCB	1.80E-03	1.67E-03	2.10E-01	2.10E-01
Marine ecotoxicity	kg 1,4-DCB	2.68E-03	2.48E-03	3.05E-01	3.05E-01
Human carcinogenic toxicity	kg 1,4-DCB	3.93E-03	3.60E-03	1.47E-01	1.47E-01
Human non-carcinogenic toxicity	kg 1,4-DCB	5.71E-02	5.29E-02	7.90E+00	7.89E+00
Land use	m2a crop eq	6.54E-04	5.90E-04	4.01E+00	4.01E+00
Mineral resource scarcity	kg Cu eq	1.75E-04	2.54E-03	6.12E-02	6.35E-02
Fossil resource scarcity	kg oil eq	5.17E-02	4.59E-02	1.11E+00	1.10E+00
Water consumption	m3	7.69E-01	6.82E-01	1.26E+00	1.17E+00

Similar tendencies can be observed for economic results, from which emerges that the addition of coadjuvant increases the share of costs for materials. At the same time, the optimization of operational times and the increase of plant efficiency entail the reduction of the incidence of fixed costs as labour, quotas, wages and other duties. Considering only the extraction process, the addition of Calcipur®5 allows a cost reduction of around 5 %. However computing also the production costs for olive production, the difference between scenarios drops to less than 1.5 %, as already seen for the environmental profile (Figure 2).

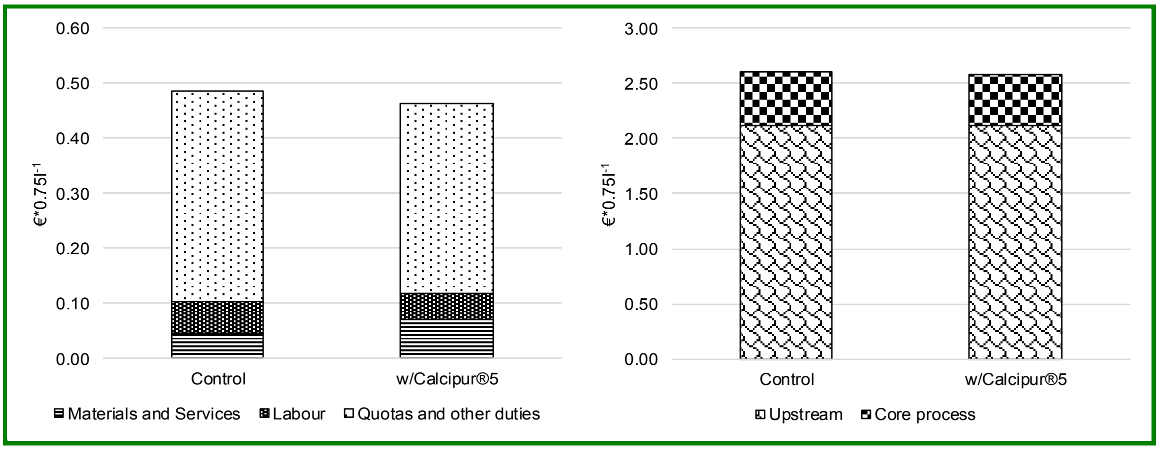

Figure 2: Results of the economic analysis

The LCC analysis of 0.75l of EVOO was computed by considering the current price of Calcipur®5 (0.40 € kg^{-1}). The price reduction for $CaCO_3$ could improve the economic performance of innovative scenario, which results affordable up to a calcium carbonate price of 0.67 € kg^{-1} (Figure 3). Unfortunately, although the $CaCO_3$ is abundant in nature, it is a natural resource and, as such, its price could increase either by reducing the quantities available or by taxing the withdrawals.

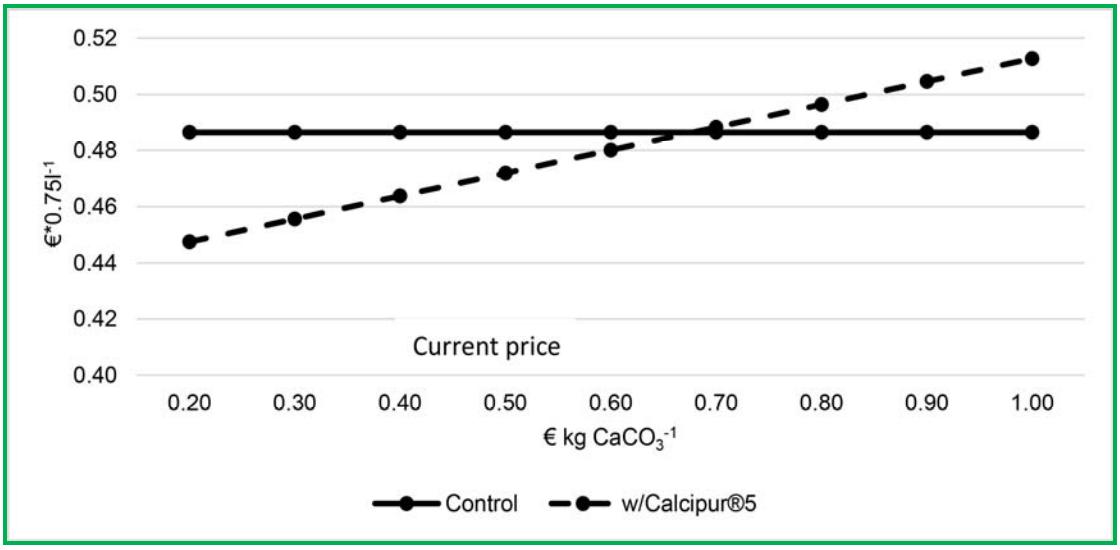

Figure 3: Break even point (BEP) in function of $CaCO_3$ market price

4. Conclusions

The objective of this study was to check the environmental and economic sustainability of an experimental technology for olive oil extraction. Trials demonstrate that the modification of rheological properties through the addition of $CaCO_3$ allows increasing the efficiency of the extraction process by maintaining the qualitative parameters of extra virgin oil. The evaluation by means of LCA and LCC methodologies confirms which the time reducing improves environmental burdens and optimizes the costs efficiency with a consequent higher profit. Results could be useful to highlight the main hotspots in EVOO production and to suggest improvements for a more sustainable management. Future studies would experiment further alternative extraction technologies with the purpose to identify optimal solutions for the specificities of several olive cultivars.

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