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Eco-Friendly Use of Tomato Processing Residues for Lactic Acid Production in Campania

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Industry has the severe problem to accumulate, treat and dispose food processing wastes and by-products. The main objective of many recent studies is to test innovative processes and technologies for recycling and upgrading these wastes for recovering high-value-added marketable materials in compliance with the European Sustainable Waste Management Guidelines and the principles of the "circular economy". In particular, new, innovative and profitable management strategies for sludgy waste from tomato processing industries could be fostered in Campania. Alternative and valuable process chains are possible in which different players working together to "eco-friendly" recycle, reuse and promote tomato industry residual biomasses could obtain high value-added products with a sustainable approach. One of the possible added value product that can be obtained by tomato industrial processing waste is lactic acid, whose production could have a remarkable economic and ecological impact.
In this study we provide an estimate of the available tomato industry processing waste and related potential for lactic acid production in Campania, carrying out a survey on the more suitable production technologies. Maximum radius distance of industries from a possible/hypothetical centralized transformation plant according to the biomass availability and transportation facilities is calculated. Feasibility studies of eco-friendly processes able to convert tomato processing waste in lactic acid are considered, evaluating the actual amount, reuse or disposal in waste dumps or soil of the tomato pomace. The benefits of the correct management of tomato processing waste is considered, evaluating the possible economic revenue resulting from the proposed system.

1. Introduction

Italy is the second biggest worldwide producer of tomato products after the United States, accounting on average for 13 % of global production and 48 % of European production with an average over the past three years of about 5 million tonnes of fresh tomatoes processed (ANICAV, 2015; ANSA, 2016). During tomato processing a waste, known as tomato pomace, which represents approximately 3-5 % wt is produced (Del Valle, 2006). It is mainly composed of skins, seeds, and vascular tissues, and results still rich in nutrients that can be used as a potential source of various marketable bioproducts (Lenucci et al., 2013). The lignocellulosic matter is the major fraction of tomato pomace representing 65 % of the total tomato fibre on dry basis (Cepeda and Collado, 2014). Tomato pomace is mainly used as animal feed, inexpensively used on the soil as fertilizer or disposed of as a solid waste (Pane et al., 2015). However, there is a great potential for a better use of this biomass, as reliable source of added value marketable products. Lactic acid (LA), in particular, has several applications in food, pharmaceutical, cosmetics, textiles as well as the production of biodegradable poly-lactic acid (PLA), a well-known bioplastic material (Panesar and Kaur 2015).

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2. LA extractive technologies

The industrial production of LA can be obtained either by microbial fermentation or chemical synthesis (Figure 1). The first method allows obtaining pure LA unlike the second method, which always leads to the formation of a racemic mixture (Ghaffar et al., 2014; Randhawa et al., 2012).
The main product underlying the chemical production of LA is lactonitrile, obtained following the reaction between acetaldehyde (ethanal), deriving from non-renewable fossil resources, and hydrocyanic acid in presence of a base. These reactions require high pressures and occur in liquid phase, and the obtained raw lactonitrile is purified by distillation. After this stage, sulphuric acid or hydrochloric acid are added to hydrolyze lactonitrile in LA and ammonium salt (Boontawan et al., 2011). The purification of the LA is carried out by distillation. However, LA is not very volatile, so its recovery after production is quite difficult. This drawback can be overcome by applying an esterification with methanol to obtain methyl lactate (Kumar et al., 2006). Finally, water is added to hydrolyze methyl lactate in LA and methanol (Boontawan et al., 2011).
As abovementioned, chemical synthesis does not allow to control the D-LA to L-LA ratio and a racemic mixture that consists of equal amount of D-LA and L-LA is formed. This latter is not suitable for poly-LA production since an amorphous polymer is produced with low melting point, which in turn becomes an obstacle to the broad range of applications (Park et al., 2010).
However, the most common method to produce LA is by microbial fermentation, but the fermentation conditions and the D (-) or L (+) LA type produced depend on the bacterial strains used (Zhou et al., 2003). L-LA is produced from carbohydrates by bacteria belonging to the genus Lactobacillus and performing homolactic fermentation (Pang et al., 2010). Additionally, *Rhizopus*, *Escherichia*, *Streptococcus*, *Enterococcus*, *Bacillus*, *Kluyveromyces* and *Saccharomyces* strains can produce L-LA. Instead, microorganisms like Leuconostoc and *Lactobacillus bulgaricus* produce D-LA (Park, 2010). Since D-LA is not metabolizable by animals, the L-LA is preferentially used in cosmetics, food industry and for preparing bioplastics. Pure L-LA can be, in fact, used for the preparation of polylactic acid (PLA), which can be subsequently transformed in crystals with a fusion point of 180 °C (Park, 2010).
The starting fermentable carbohydrates are mainly represented by glucose, sucrose, lactose and starch/ maltose derived from feedstocks. The most important techniques used for the purification of LA from fermentation broth are ion exchange, reactive extraction, membrane technology, distillation and electro-dialysis (Gonzalez et al., 2007). The price, availability and the relative purification costs of the produced LA justify the choice of renewable resources, which should properly pre-treated and used as a feeding material for microbial fermentation (Ghaffar et al., 2014).

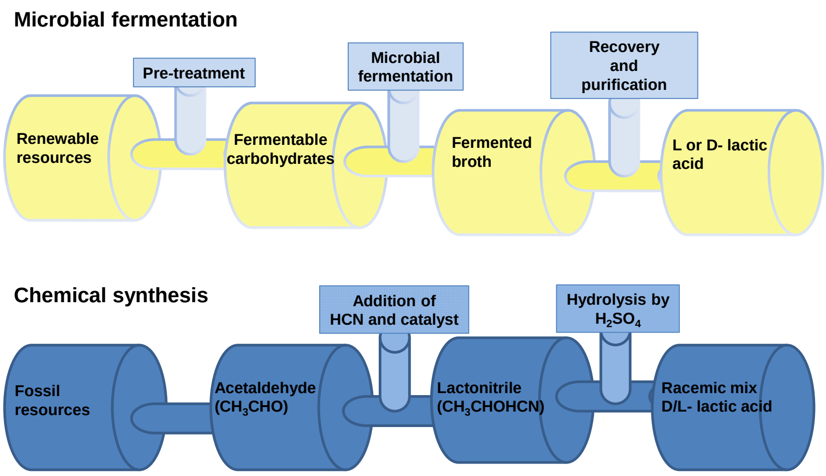


Figure 1 Production of L and/or D-lactic acid by microbial fermentation or chemical synthesis

3. Available tomato industry processing waste and related potential for LA production in Campania

The South-Center Italy tomato processing industries belonging to ANICAV (National Association of Industrialists of Canned Food Plants, representing companies involved in the processing and storage of plant products) are eighty five. Seventy out of eighty five are placed in Campania region. They are subdivided in four production segments: i) <0.2 kt (43), ii) 0.2-0.5 kt (29), iii) 0.5-1 kt (9), iv) >1 kt (4). The tomato products

are concentrated tomato paste (6.7 %), whole peeled tomato (40.6 %), tomato pulp (35.4 %), tomato puree (12.9 %) and others (1.4 %). Tomato production starts at the beginning of July and ends in the first decade of October. The eighty-five ANICAV industries have processed in the last 6 years (2012-2016) about 139 kt tomatoes, with an average of around 23 kt per year. The percentage of organic residues produced during tomato processing is around 3 to 5 % wt., and it is typically generated as waste. It is constituted by a mixture of tomato peels (1.5-2.5 % wt), crushed seeds (1-1.5 % wt), small amounts of pulp remaining after processing and "organic green" (leaves, parts of plants) around 1 % (Brachi 2016, Heuzé et al. 2015). Tomato pomace composition (in dry weight basis) is as follows: 59.0 % fibre, 25.7 % total sugars, 19.3 % protein, 7.5 % pectins, 5.9 % total fat and 3.9 % minerals (Del Valle et al. 2006). The lignocellulosic matter is the major fraction of tomato pomace representing 65 % of the total tomato fibre on dry basis (Cepeda and Collado 2014). In particular, it contains around 15 % of dry mass as cellulose, 10 % hemicellulose, and 40 % as total lignin, where the acid-insoluble lignin is about 36.4 % (Kehili et al. 2016).
Since the production of this waste is seasonal and linked to the harvest period, mainly concentrated in two-three months of the late warm-season, the daily production rate of these residues is very high and, consequently, its management causes severe problems to the manufacturing companies (Mangut et al., 2006). However, In order to plan the recovery of LA from tomato processing wastes and residues, we accounted for the whole quantity of tomatoes used by ANICAV tomato industries in Campania for producing mainly whole peeled tomato (40.6 %) and tomato pulp (35.4 %). ANICAV evaluated the average amount of tomatoes used by such industries as about 2 Mt/year in the period 2014-2016. Leoni (1997) gives a detailed estimate of residues arising from the tomato manufacturing industries. The author identifies two main categories: 1) tomato processing wastes and 2) other different types of waste, removed before processing tomatoes. These latter are the mineral material other than tomato (MMOT), the vegetable material other than tomato (VMOT), the unripe tomatoes and the tomato seriously damaged by mechanical and other reasons. Percent values of waste produced before and during tomato processing and accounting for the mass balance (Figure 2), are reported in Table 1.

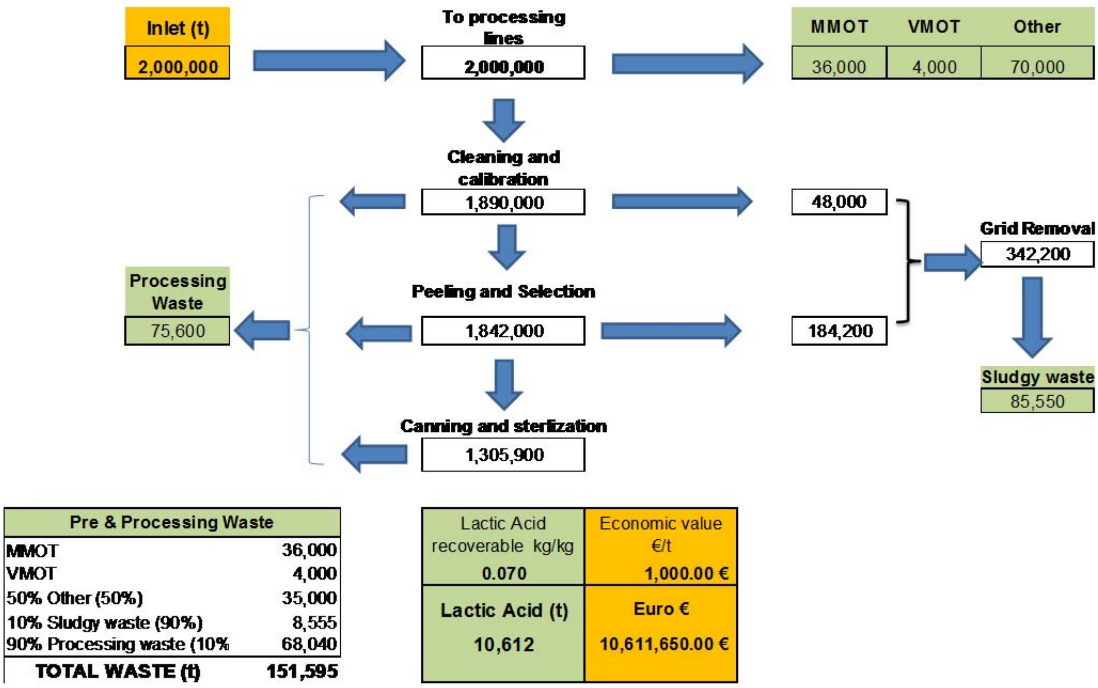


Figure 2 Mass balance for tomato processing industries in Campania (ANICAV data) and recoverable LA (t)

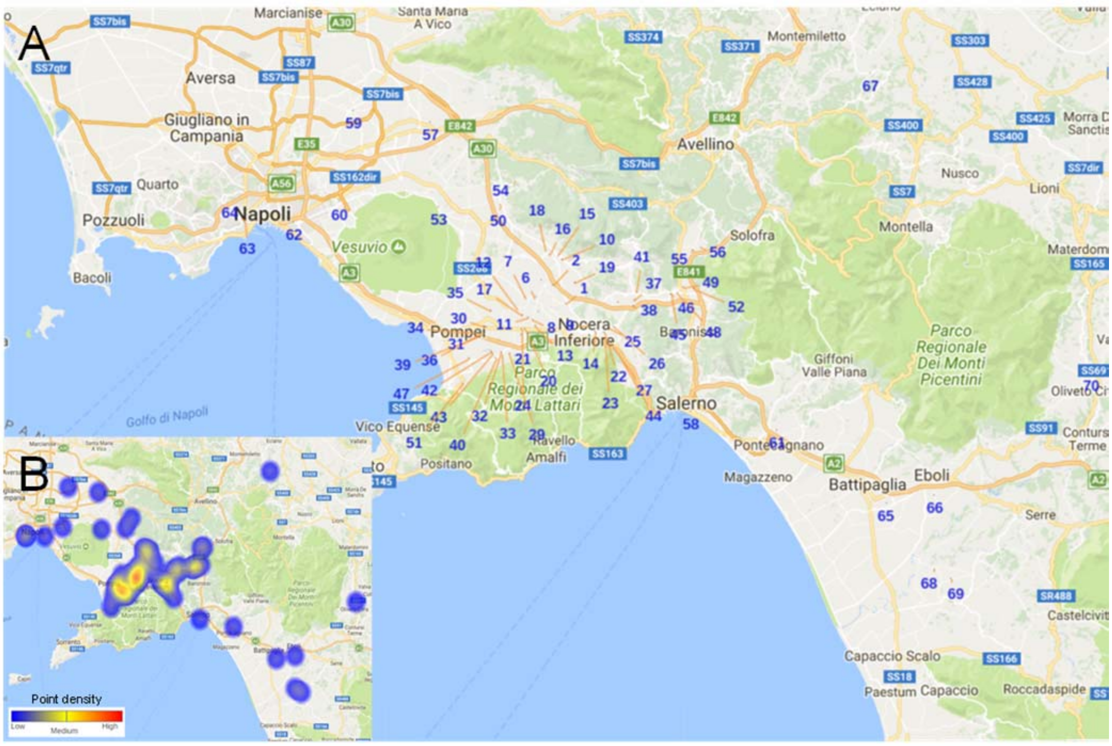
Table 1: Percent values of resulting Tomato Waste pre and processing waste (Leone 1997)

MMOT	VMOT	Squashed and dumped tomatoes	Unripe tomatoes	Processing Waste
1.80 %	0.20 %	6.00%	1.00 %	4.00 %

Considering the estimates reported in Leoni (1997), the processing residues are about 75.6 kt, whereas the pre-processing tomato wastes account for about 83.5 kt. These values should take into account different humidity values of the diverse types of wastes to be dealt with. The employed values of humidity are reported in percent values in parenthesis in Figure 2 near each type of waste. The quantities of wastes actually employed for LA recovery represent the dry fraction of each waste.
Such residues and wastes can basically produce about 0.07 to 0.14 kg of LA (Pleissner et al., 2017) per kg of tomato residue, thus about 10.6 kt to 21.2 kt of lactic acid starting from about 152 kt of dried wastes. The gross economic revenue can be estimated equal to about 10.6 M€ to 21.2 M€, considering the market cost of LA equal to about 1000 €/t. In Figure 2 the case with 0.07 kg of LA per kg of tomato wastes is shown, i.e. the least favorable one.
Of course, a correct economic evaluation should account for the cost of plant and the running costs which occur during the working period of the plant itself. Anyway, such a revenue could be interesting if a centralized plant is going to be built and the transport costs for delivering these wastes to the plant are minimized. To this end, the evaluation of the best plant location is carried out in order to minimize the driving distance from each tomato industry to the LA extraction plant.

4. Tomato processing industries Radius and transportation facilities

The determination of maximum radius distance of tomato processing industries for a centralized extraction plant should take into account mainly geographic, economic and social factors, including vehicles fuel consumption and pollutant emission during biomass collection and transport. However since the impact is mainly dependent on distance/time from the centralized plant, the lowest route is recommended and it is possible to calculate it by a geographic information system (GIS). We used for our localization and radius analysis the data related to the industries belonging to ANICAV. It associates in Italy currently about one hundred fifty companies mainly involved in tomato processing which are responsible of around 50 % of all processed tomato in Italy. Seventy out of them are placed in Campania region (Figure 3 A, B).



The maximum radius distance of industries from a hypothetical centralized transformation plant according to the biomass availability and transportation facilities has been calculated using the Espatial mapping software (Espatial, 2017). The average drive distance of all industries from the hypothetical centralized plant placed in Fosso Imperatore (SA) is 18.9 km, with an average driving time of about 17 minutes. Forty industries out of seventy have a maximum distance from the possible centralized point of 12 km with a maximum driving time of 15 minutes (Figure 3C).

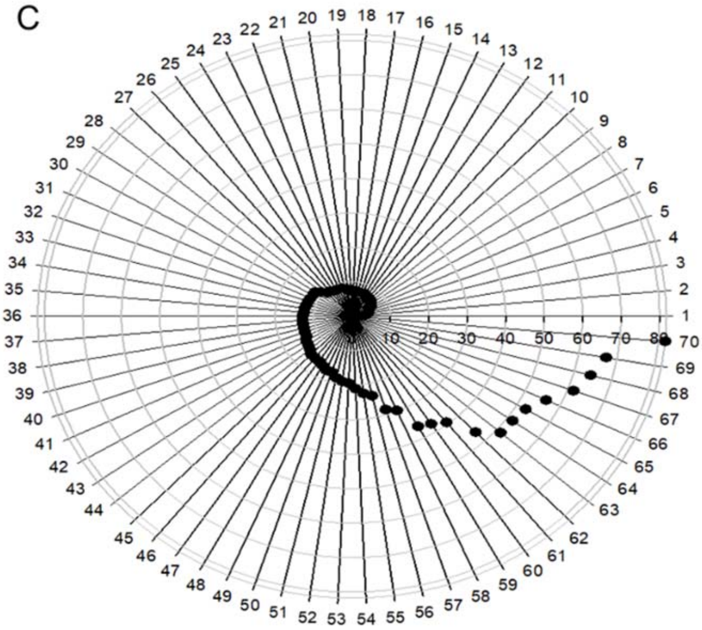


Figure 3 ANICAV tomato processing industries as A) located in Campania region, B) point density heat map, C) radar plot of radius (km) vs. company

5. Greenhouse gas emissions and water pollution deriving by tomato waste mismanagement

Tomato as well as other vegetable processing residues are currently used as low-value livestock feed (Anicav 2016) or mostly disposed of as a solid waste (Zuorro et al., 2014). Compliant with Italian legislative requirements, such residues can also be inexpensively disposed directly on the soil as fertilizers (Pane et al., 2015), contributing to maintain the carbon feedstock of the soils. However, the wastewater produced by the tomato industries deteriorates quickly, and this disposal on the soil can cause water pollution, rotten odours, as well as it contributes to increase the greenhouse effect due to the uncontrolled decomposition and release into the atmosphere of large amounts of carbon dioxide and methane (Mangut et al., 2006). In some countries, tomato pomace is still dumped in waterbodies near the factory or left to accumulate on soil close the production site. In this way it becomes a breeding place for insects like flies and mosquitoes, acting as vectors for a wide range of viral and parasitic infectious diseases (Caluya et al., 2000).

Even when used as feed for animals, tomato pomace has the same drawbacks of other organic biomasses, that is high volumes, expensive transport, rapid deterioration, low nutritional value. Its water content can vary from 80 to 98% and the deterioration time can be lower than 2 days depending on temperature. Therefore, it must be dried and/or ensiled before being used for feeding animals (Cotte, 2000). Since it is sold at a nominal price of 5 €/t as animal feed, there is no convenience for industries in this use.

6. Conclusions

The valorization of this accessible, yet underutilized resource, for production of LA, an added value product, can contribute to create a circular economy and a smart and efficient use of renewable resources. It is important to enhance in industrialists and consumers the consciousness of the concepts that the produced “waste is not waste” and that this “waste hidden benefits”. The profitable use of wastes as resources could not only minimize pollution protecting the environment, but it could also economically benefit industries and supports a strong local economy opening new job opportunities all along the waste to bio-products chain.

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