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Thinking, modelling and assessing costs of extracting added-value components from tomato industrial by-products on a regional basis

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This contribution is a piece of work within a more comprehensive research program dedicated to a thorough exploitation of industrial tomato by-products, which should be technically feasible, economically convenient and environmentally friendly. In this respect, the proposed paper focuses three aspects of newer and broader interest: lycopene extraction, cutin separation and compost production. The investigated case study refers to the tomato industry in the Campania region (IT).
The lycopene extraction from peels is usually carried out by a solvent- or supercritical CO_2-assisted operation; the separation of cutin is performed in two process steps: alkaline hydrolysis and acidification. The solid residual, after cutin separation, is proposed to be used as feedstock for composting, not alone, but mixed with other suitable biomass to adjust both the final moisture content and C/N ratio. To this end, two scenarios according to the "biorefinery cascade approach" were developed that differ in the extraction technology for lycopene, i.e., 1) an optimized organic solvent; 2) CO_2 as a supercritical fluid. The proposed process block diagram takes into account the upstream separation of peels from seeds and the downstream composting of seeds and residual solids (i.e., after lycopene and cutin extraction) in both scenarios, which were set up and quantitatively evaluated, under both viewpoints of process feasibility and economic sustainability. The mass and energy balances were written for all the involved process steps; the balance equations and the mathematical calculations were implemented and solved in MS EXCEL®.

1. Introduction

Italy is the 2nd country in the world for tomato transformation after USA, due to 5 million tons of processed fresh fruits every year (ANICAV, 2020). The Campania Region, due to its long-standing experience, is the main and biggest production pool regarding the transformation of tomato in Europe; it is reported (ANICAV, 2020; ISTAT, 2020) that companies, operating in this region, process almost half of the Italian tomatoes for industry, namely 2.52 Mton of fresh fruits transformed every year.
The transformation of tomato leads to a huge amount of residues, tomato pomace being the most abundant. This by-product can represent even the 10% (Cappelli and Vannucchi, 1998; Knoblich et al., 2005) in weight of the processed tomato, with a high moisture content in the range 69-90 % by weight (Silva et al., 2019). It is estimated that 76 ktons of tomato by-products are produced every year in Campania. However, their generation concentrates in only two summer months, according to the seasonality of the tomato supply chain.
Tomato pomace is composed by a mixture of skin and seeds, it is a processing residue, but carries an enormous variety of high-value compounds, e.g., carotenoids and antioxidants (Knoblich et al., 2005; Staj•i• et al., 2015). Unfortunately, it is disposed of without any income for the tomato transformation companies, that is as animal feed or in the worst case sent to landfill, thus wasting high-value compounds and contributing to earth pollution (Heuzè et al., 2015). In principle, tomato processing by-products could be exploited through thermochemical, biological and chemical conversion to obtain biogenic fuels and then electricity and heat (Brachi et al., 2018; Mangut et al., 2006), even if the possibility of produce compost from this solid residue has been successfully

performed at industrial scale (Alkoaik et al., 2018; Kulcu, 2014). Anyway, it is undoubtedly convenient to extract and recover, before composting, the high-value compounds present in the pomace. The most interesting components contained in pomace are lycopene, which is the most abundant carotenoid in peels and is well known to be the most powerful antioxidant with beneficial effect on cancer and cardiovascular disease (Di Mascio et al., 1989; Knoblich et al., 2005); and cutin, which is the main building block of the plant cuticles and can be used as starting material for biopolymers (Cicognini et al., 2015; Cifarelli et al., 2019).
In this work, starting from this background, a biorefinery scheme for complete valorization of tomato by-products is developed. The model includes three main operations: lycopene extraction, cutin based-polymer production and composting of the solid residues. Technical and economic feasibility are investigated.

2. Materials and methods

2.1 Feedstock characteristics and composition

Datasets from Italian National Institute of Statistics ("ISTAT") and Associazione Nazionale Industriali Conserve Alimentari Vegetali ("ANICAV"), regarding production and transformation of tomato in Italy, were used to evaluate the amount of residual peels produced every year in Campania region. Indeed, ISTAT reports that in the last decade in Italy an average of 5.05 Mton of industrial tomatoes are transformed every year. In accordance with ANICAV, half of industrial tomato is transformed in Campania, namely, 2.52 Mton. Moreover, taking in consideration the literature data, reported in the following Table 1, the amount of lycopene-based oleoresin, cutin and compost that it would be possible to produce from tomato by-products were evaluated.

Table 1: Literature data and assumptions for lycopene and cutin extraction and compost production

	[%w/w]	References
Content of tomato by-products on the whole fruit	3	(Cappelli and Vannucchi, 1998)
Content of tomato peels on by-products	60	(Silva et al., 2019)
Moisture content in peels	80	(Brachi et al., 2016)
Oleoresin mass fraction on dry basis in peels	5.21	
Cutin yield on dry basis	28	
Mass fraction of manure needed for composting	30	(Kulcu, 2014)
Mass fraction of wheat straw needed for composting	10	
Compost yield	20	(Environmental Footprint database, 2020)

2.2 Development of block diagrams for the scenarios

Two different scenarios were developed to evaluate the economic feasibility of a single plant biorefinery based on industrial tomato by-products and located in Campania. In the models the tomato by-products are collected at transformation plant, transported to the biorefinery and stored in cold condition (cold rooms at −23°C, 2.1 m^3 each). Firstly, peels and seeds are separated from the pomace in flotation-cum-sedimentation system designed by Kaur et al. (2008), where 5 kg of water are needed for each kg of pomace. Seeds are sent to composting while skins undergo extraction steps. First, lycopene-based oleoresin is extracted. Two techniques were compared: solvent extraction by organic solvent mixture and supercritical fluid extraction. The oleoresin production method patented by Kumar and Sherena (2016) was used to estimate solvent extraction yield and parameters. Namely, wet tomato skins are soaked with hexane-ethanol mixture, 40:60, for 2 hours at RT with solid/liquid (S/L) ratio of 1:6, then the extracted oleoresin is washed twice with the same solution (S/L 1:5). The oleoresin is purified by vacuum drying (at 60°C (3 m^3, 6 kW). The extraction yield is 1.7 g of oleoresin per kg of wet skins, with a concentration of lycopene of 10.21% in the final oleoresin. Regarding CO_2 supercritical extraction, the method proposed by Pellicanò et al. (2019) was used as reference. In their work lycopene-based oleoresin is extracted from dried tomato skin at 550 bars and 60°C for a contact time of 40 min. They reported an extraction yield of 11.12 g of oleoresin per kg of raw material (without drying) with a lycopene content of 15.36%. As a second step, peels are subjected to cutin extraction by the method proposed by Benitez et al. (2018). Namely, dried tomato peels are hydrolyzed by NaOH aqueous solution (0.5 M) at S/L 1:50 kg/L, 100°C for 6 h, then filtered. The non-hydrolizable residue, constituted by hemicellulose and cellulose is sent to composting. The surnatant solution is acidified with HCl (10%) at S/L 1:10 kg/L, then the precipitated cutin is filtered and washed with water at S/L 1:50 kg/L. In this way cutin resin, available for polymerization like a polyester resin, is obtained with 30% yield on dry basis. Therefore, seeds from sedimentation and the non-hydrolysable residue are mixed with manure and wheat straw, to reach optimal C/N ratio and moisture content and sent to composting in bioreactor following the procedure developed by Kulcu et al. (2014). In particular, to reach a moisture content of 40-60% and a C/N ratio of 20-30, the optimal mixture should have 60% of tomato by-products, 10% of wheat straw and 30% of manure. The compost yield of 20% is reported in the

"Environmental Footprint database" by the European Commission's Single Market for Green Products Initiative (Environmental Footprint database, 2020).
The block flow diagram of the two different scenarios with the unit operations are reported in Figure 1.

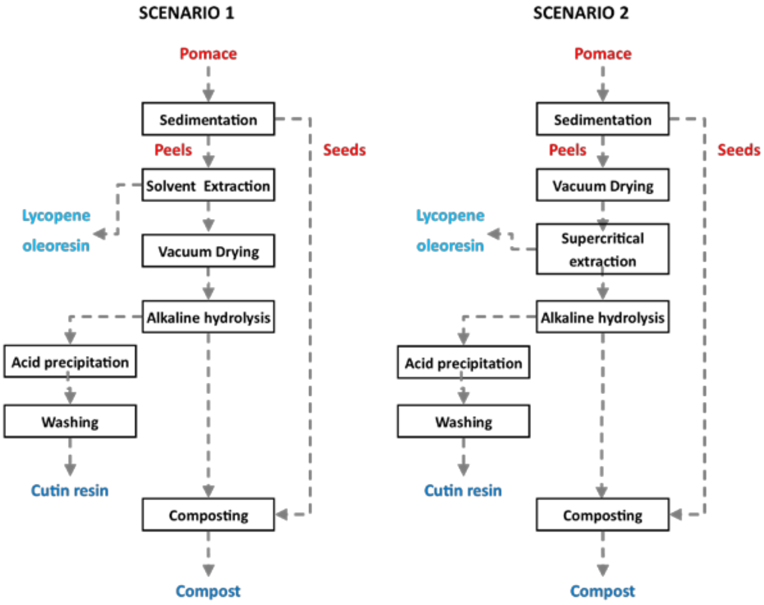

Figure 1 Block process flow diagram of the two developed scenarios

3. Results and discussion

At the beginning of this work, after feedstock characteristics and processes yield were gathered from literature, a general mass balance on tomato by-products was carried out. It was found that, starting from a calculation basis of 100 ton of tomato by-products, it is possible to extract 0.7 ton of lycopene-based oleoresin, 3.3 ton of cutin. Moreover, it is possible to send 158 ton of biomass (including tomato by-products) to composting, producing 33 ton of compost and generating 125 ton of emissions to air and soil (including moisture) due to the degradation reactions occurring during the composting.
The results obtained from the mass balance are reported in the Sankey diagram in Figure 2.

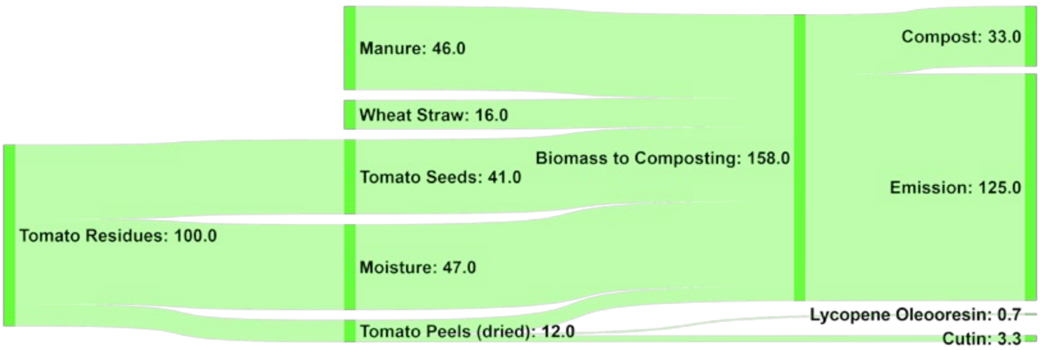

Figure 2 Mass balance for tomato by-products utilization and conversion (basis 100 ton of tomato residues)

Taking into consideration the two developed scenarios and the tomato by-products available in Campania at a rate of 76 kton/y, it was possible to evaluate the amount of the three compounds produced by the biorefinery in the two different scenarios, and therefore the net value of the products. In the following tables the results of the analysis are reported together with the value of the compound on the market and their benchmark.

Table 2: Biorefinery products amount per year and their value on the market (basis 76000 ton/y of tomato residues).

Product		**Amount [ton/y]**	**Value [€/kg]**	**Benchmark**
Lycopene oleoresin	Scenario 1	77.3	91.7	Lycopene oleoresin for health care from Quanao Biotech Co.
	Scenario 2	505		
Cutin resin		2727	7	General purpose polyester from US Composites Inc
Compost		24000	0.023	Green compost from Cold Creek Compost Inc.

With this gathered and evaluated information, it is possible to calculate the gross sales (i.e., the sum of all sales during a year neglecting returns, allowances, and discounts) for the modelled biorefinery in the two different scenarios. It is clear that the gross sales would be higher for Scenario 2, due to the higher production of lycopene; namely, the Scenario 1, with solvent extraction, has sales of 26.7 M€/y, while Scenario 2, with supercritical extraction, has sales of 65.9 M€/y.

Then, to understand the feasibility and profitability of the two modelled biorefineries, the gross profit, namely the difference between the gross sales and the production cost, was evaluated. The production cost was estimated by evaluating the expected operating costs of the most important unit operations of the biorefinery. For this reason, the following operations were taken into account: transportation from the transformation plant to the biorefinery site, preservation in freezing condition, vacuum drying of the residues, extraction either with solvent or supercritical fluid, cutin production and composting. In the following Table 3, the estimated cost of the single operations and the procedures and references used for evaluation are reported.

For the calculations, 350 working days per year and 16 hours per day were assumed. The energy cost has been always taken as 0.071 €/kWh.

Table 3: Annual cost of single operations in biorefinery scheme

	Expense [M€/year]	**Procedures and References**
Feedstock	-	Tomato by-products are accounted as expense for transformation company, therefore is sold for free
Transportation	0.120	Transformation plant positions are gathered; a mean distance from an industrial area is evaluated and a fleet of medium and heavy-duty truck, diesel-engined, is assumed
Preservation	0.1	A battery of commercial cold rooms (at −23°C, 2.1 m^3 of volume each, 700 W); the number of actually working rooms decreases linearly with time
Vacuum drying	0.34	A battery of commercial batch dryers is assumed (10 kg load, 6 kW), with 1 h drying for complete removal of moisture (Abano et al., 2012)
Solvent extraction	3.5	As reported in literature solvent extraction of lycopene, considering batch distillation or vacuum drying of oleoresin, is around 45 €/kg of lycopene (Saini and Keum, 2018)
Supercritical extraction	300	As reported in literature the cost of production for supercritical extraction of lycopene is 1.8 k€/kg of lycopene, corresponding to 0.5 k€/kg of oleoresin (Bastidas-Oyanedel and Schmidt, 2019; Rocha-Uribe et al., 2014; Silva et al., 2014)
Cutin resin production	7.9	The expense accounts the cost of the raw materials used for the hydrolysis and acidification, and wastewater treatment cost for industrial sludge
Composting	0.27	Electricity demand is considered. Three steps are taken in account: shredding (with industrial shredder, 30 kW, 1 ton/h), bioreaction in an aerated and agitated batch reactor (Hensirisak et al., 2002; Karlsson et al., 2016) for 108 h/batch (Alkoaik et al., 2018) and sieving (with industrial machine,15 kW, 3 ton/h)

The first outcome, which it is clearly understandable for gross sales and production cost, is that the super critical extraction of lycopene oleoresin is not profitable due to high operating cost of this technology. This conclusion is consistent with results obtained by BIOACTIVE-NET project (Final Report Summary - BIOACTIVE-NET, 2008). Moreover, it must be noticed that using supercritical CO_2 could be convenient and profitable to produce pure lycopene, due to the high price (174 $ for 1 mg of lycopene 90% pure from tomato). Regarding the case based on solvent extraction, the gross sales and the production costs are graphically reported in Figure 3.

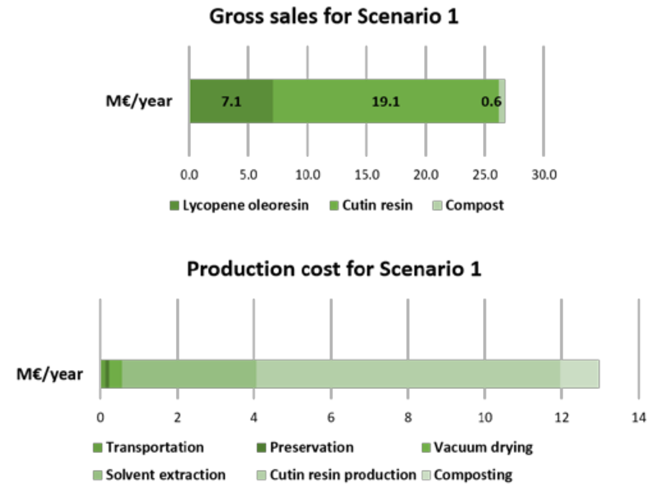

Figure 3 Split of gross sales and production cost for the 1st scenario

Figure 3 shows that lycopene extraction and cutin production allocate almost all of both income and expense; anyway, composting, even if it is not highly profitable, is necessary because it avoids the landfilling of residual solids. From the above calculations, it is possible to evaluate the gross profit of the process (i.e., the difference between revenue and the cost of making a product or providing a service, before deducting overheads, payroll, taxation and interest payments). In particular, a biorefinery based on the technologies described in this work and using tomato by-products to produce lycopene oleoresin by solvent extraction, cutin resin and compost would have a gross profit of 14.5 M€/y. This value represents a proof that a better exploitation of tomato by-products is possible, whereas at present this biomass is considered a problem to face and not an asset.

4. Conclusions

Two biorefinery scenarios were set up for the by-products resulting from the annual industrial transformation of fresh tomatoes in Campania, that is 76 kton/y and 2.52 Mton/y, respectively. The scenarios were quantitatively evaluated, under both viewpoints of process feasibility and economic sustainability. The results indicate that 2.7 kton/y of cutin and 24 kton/y of compost could be produced every year; moreover, 77 ton/y and 505 ton/y of lycopene oleoresin could be extracted in the Scenario 1 and 2, respectively. Using the current market values of the two products, the gross sales were quantified at 26.7 and 65.9 M€/y for Scenario 1 and 2, respectively.
Then, the annual production costs were evaluated by taking into account the following steps: transportation from the processing plant to the biorefinery site, preservation in frozen conditions, vacuum drying of the residues, lycopene extraction with either a solvent or supercritical fluid, cutin production and composting. Finally, the gross profit was evaluated and discussed. Scenario 2 has a negative gross profit, mainly due to the high operating cost of supercritical technology: hence, a biorefinery based on this option is not viable. Scenario 1, on the other hand, has a gross profit of 14.5 M€/y, meaning that a biorefinery scheme based on conventional extraction is profitable. Therefore, tomato by-products can be turned from a problem into a useful resource for the Campania region in the frame of a circular economy approach. The same reasoning can be hopefully extended to other regional districts in which tomato industrial transformation is intensively carried out, also in other parts of world.

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