MLS - HEALTH & NUTRITION RESEARCH (MLSHNR)
http://mlsjournals.com/Health&nutritionrsearch-Journal
ISSN: 2603-5820

Health & Nutrition Research

(2024) MLS-Health & Nutrition Research, 3(1), 4-23 doi.org/10.60134/mlshn.v3n1.

VALORIZATION OF FOOD WASTE FROM TOMATO PROCESSING (SOLANUM LYCOPERSICUM)

VALORACIÓN EN EL APROVECHAMIENTO DEL RESIDUO ALIMENTARIO DEL PROCESADO DEL TOMATE (SOLANUM LYCOPERSICUM)

Carlota Anaya Pérez
Universidad Europea del Atlántico, Spain (carlotaanaya@hotmail.com) (https://orcid.org/0000-0003-1656-1366)

Manuscript information:

Recibido/Received: 20/07/2023
Revisado/Reviewed: 28/08/2023
Aceptado/Accepted: 12/02/2024

ABSTRACT

Keywords:
Tomato valorization. literature review, bioactive compounds, food waste, food industry.

The consumption of Solanum Lycopersicum, commonly known as tomato, has increased in recent years. As a result, the production and consequently the waste generated from it, as well. The present work aims to determine whether there are significant differences between the different methods of valuation in the use of tomato food waste, as well as its practical application. In order to find out, a bibliographic review was carried out through which a total of 52 articles published in the last five years were selected. Of the total, twelve focused on the extraction of carotenoids, ten on the extraction of phenolic compounds, four on pectin and seven on the formation of biogas, as methods for the valorization of the raw material. Although the food valorization of tomato is wide and little studied yet, it was observed that the extraction of phenolic compounds, pectin or lycopene represent a wide range of new possibilities with the use of emerging pretreatment methods such as high pressures, electric pulses or supercritical CO2. The conclusion is that even though more studies are needed, emerging methods are more effective for the extraction of active compounds from tomato.

RESUMEN

Palabras clave:
Valorización del tomate. revisión bibliográfica, compuestos bioactivos, desperdicio alimentario, industria alimentaria.

El consumo de *Solanum Lycopersicum*, conocido comúnmente como tomate, se ha visto incrementado en los últimos años. Por ello, la producción y en consecuencia el desperdicio generado a partir de él, también. El presente trabajo pretende propiciar si existen diferencias significativas entre los distintos métodos de valoración en el aprovechamiento del residuo alimentario del tomate, así como su aplicación práctica. Para poder conocerlo, se realizó una revisión bibliográfica a través de la cual se seleccionaron un total de 52 artículos publicados en los últimos cinco años. Del total, doce se centraron en la extracción de carotenoides, diez en la extracción de compuestos fenólicos, cuatro en la pectina y siete en la formación de biogás, como métodos de valorización de la materia prima. Aunque la valorización alimentaria del tomate es amplia y poco estudiada aún, se pudo observar que la extracción de compuestos fenólicos, pectina o licopeno suponen un gran abanico de nuevas posibilidades con el uso de métodos de pretratamiento emergentes como las altas presiones, los pulsos eléctricos o el CO2 supercrítico. Llegando a la conclusión de que aun observando la necesidad de mayor número de estudios, los métodos emergentes son más eficaces para la extracción de los compuestos activos del tomate.

Introduction

The consumption of fruits, vegetables and greens throughout history has always been high. During the last few years, due to various situations such as the search for health improvement, some vegetables, for example, the case of tomatoes, have seen an increase in demand. This increase in demand in turn implies a need to increase production, resulting in an increase in the waste generated as a result of its processing (1-4).

Due to this increase in food waste and other related issues, the European Union has approved various proposals such as the green pact or the 2030 agenda, some of which aim to promote the recovery of food by-products. (1,5,6).

Objectives

The general objective is to determine whether there are significant differences between the different methods of valuation in the utilization of tomato food waste, as well as their practical application. Therefore, the following specific objectives are proposed:

- Promote new emerging methods of recovery in the use of tomato waste.
- To establish whether there are significant differences between the different methods of by-product utilization.
- To demonstrate the different methodological characteristics for the use of tomato products.

The tomato industry

According to the FAO, in 2019, the amount of food waste worldwide of fruits and vegetables was 1300 million tons, being therefore, one of the sectors that generated the most waste, with up to fifty percent of waste during the periods between harvesting and food production (1,7,8). Consequently, in the 21st century there are important challenges linked to food safety and the need to reduce food waste at the global level, promoted by various organizations, including national governments and the FAO (1,4,6,12).

Globally, the growth of the Solanum lycopersicum industry has steadily increased in recent years, resulting in the production of a considerable amount of waste derived from the increase. The global increase in the production of said raw material between 2019 and 2020 was 2.4%, with a total of 38,282 million kilograms of tomato at industrial level. Food waste from this vegetable is large and has a negative environmental impact due to the processes involved in handling, conditioning and processing (5,7,9-12).

The reduction of materials derived from treatment and their use as new raw materials to obtain new value-added products is a change that must take place in order to obtain a circular economy and that such a level of global waste is not generated, assuming the valorization of most of the products. In addition, the demand for bioactive compounds among the population for their health benefits continues to grow every year, and they can be extracted from foods such as tomatoes. Among the main consumer demands are antioxidants, phenolic compounds and phytochemicals (1,4,6,8,10,12).

Tomato by-products

Tomato by-products can be classified according to the process in which the surplus is created or according to the industrial use of the by-product, so there are two main classifications: by-products according to their origin and by-products ac20cording to their industrial use (13-15)

Depending on the origin, three categories are distinguished: industrial processing by-products, harvest or post-harvest by-products and tomato crop by-products. As the name itself refers, they are related to the production process in which the tomato is found. It should be noted that the last group includes tomato crop by-products, which include tomato pruning residues, i.e. the vegetable matter eliminated throughout the life of the plant for proper development and the tomato plants at the end of their life cycle. When plants are no longer productive and are removed from the field, the by-products have different applications including animal feed, the creation of bioplastics, fertilization or energy generation (4,13,16,16,17).

According to the industrial purpose for which the product is intended, tomatoes are classified into five groups: human food, animal food, bioplastics formation, energy generation and soil improvement (13-15).

It is worth mentioning that the food industry is currently focused on the creation of functional ingredients or nutritional supplements for humans. Functional ingredients are used to enrich foods and beverages. The main compounds used are lycopene, dietary fiber and antioxidants. All these compounds can be extracted from the plant, from areas such as the husk and seeds, which are rich in bioactive compounds (3,13,18-21). In addition, among the most commonly used for valorization, others such as FC, pectin and the formation of bioethanol or biogas for use in the generation of electricity (2,4,7,12,12,22-24) are also noteworthy.

Valorization of carotenoids

Carotenoids are isoprenoid pigments that are synthesized in all organisms that photosynthesize. Carotenoid compounds are essential for the photosynthetic apparatus and perform a powerful role as antioxidants and light-harvesting pigments. (12,20,25,26).

Lycopene is a symmetrical triterpene molecule, composed of eight isoprene units. It is an important intermediate for the synthesis of important carotenoids. Among those with a higher amount of lycopene and being the main source of natural lycopene are tomato, watermelon, gac, Southeast Asian fruit, and grapefruit (8,19,25,27,28).

In the extraction methods, there are the traditional and the modern or sustainable methods of extraction. Traditional lycopene extraction has been extensively studied, in this method organic solvents are used. Studies such as that of Almeida et al. (12) use hexane and ethanol for the extraction of carotenoid compounds, others, such as the study by Górecka et al. (21) make use of some others such as methanol, acetonitrile or dichloromethane. These types of compounds are considered analytical grade solvents with which significant information on the extraction of compounds can be obtained. According to some studies (8,10,28), the use of traditional methodology is not optimal because of its low performance and efficiency in the process, requiring large amounts of solvent and time, this was done with organic solvents so that it could pass through the membranes. Therefore, alternatives have been sought that are less harmful to the environment and more efficient in the process of obtaining the compound (12,21,29).

Among the non-conventional methods, part of the literature reviewed (8,26,27,30) mentions electric pulses (PEF) as a pretreatment method for the extraction of lycopene and β-carotene, together with the use of solvents that have a low environmental impact, which translates into beneficial effects on membrane permeabilization and thus the uptake and recovery of the target compounds. This type of technique is mainly used on the peel of tomatoes, although it is not the only part where it is performed. The study by Coelho et al. also cites the use of ohmic technology for the extraction of bioactive compounds. The use of this technology focused on heat production was used as a pretreatment prior to the achievement of the component (8).

On the other hand, methods such as high-pressure homogenization (HPH) (31), water-induced hydrocolloid complexation (WIHC) (25), ultrasound-assisted extraction (UAE), microwave extraction (MAE) and pressurized liquid extraction (PLE) (32) are cited.

Valorization of tomato pectin

Pectin is a branched heteropolysaccharide of galactose found forming the walls of plants. It is a compound with high food availability and low economic production requirements. In 2019, it was one of the most widely used biopolymers worldwide. Its main current uses are as a gelling agent, thickener and stabilizer in beverages and foods due to its physicochemical properties that make it capable of forming hydrogels. In tomatoes, it is found in the skin in higher concentrations and in the interior of the tomato in smaller amounts (20,22,33-35).

According to the most relevant studies of recent years, the extractive methods of this compound are, as in the case of carotenoids, of two types: traditional or non-conventional. Within the first group, there is the use of solvents as is the case in the article by Ninčević et al. (34) in which hydrochloric acid, sodium chloride or sulfuric acid are used to obtain pectin. Hydrolysis and subsequent extraction take place (20,22,33,34).

Among the non-conventional methods, some researchers (22,25,36) seek methods with which the use of solvents is less or even non-existent. On the one hand, there is the study in which five types of ultrasound are used: UAE, MAE, ohmic heating assisted extraction (OHAE), ultrasonic microwave assisted extraction (UAME) and ultrasonic ohmic heating assisted extraction (UAOHE). With all of them, the aim is to know which is the most efficient within the extractive techniques of the element in order to achieve, in addition, optimization and efficiency in the process (36). On the other hand, research such as that carried out by Pirozzi et al. (22) in which use is made of HPH and mild solvents in order to obtain an improvement in the obtaining yield (22). Finally, the study by Nagarajan et al.(25), mentioned in the previous section, where by means of WIHC, extraction was sought with the formation of a complex between carotenoids and pectin (22,25,36).

Valorization of phenolic compounds and antioxidants

FCs are one of the most common groups of secondary metabolites within the dietary phytochemicals belonging to plant tissue of plants. The concentrations of these compounds in the tomato plant are usually less than one percent of the dry weight of the plant, which is a very low percentage compared to other compounds. Phenolic compounds are considered essential because of the benefits to both the plant and humans. FC are part of the plant's defense against extreme temperatures or radiation, and in humans they have antioxidant properties that contribute to delaying the development of degenerative diseases (25,37,38).

Traditional methods are still used in the food by-products industry (12,39), seeking, as in the study by Almeida et al., the valorization of the compounds generated in the extraction as a possible source of biogas.

In emerging methods, the most commonly used recovery methods are those of the peel, seeds and all tomato waste without discrimination. For their recovery, methodologies such as high-voltage cold plasma (HVACP), freeze-drying, subcritical and supercritical CO2 and some others already mentioned above, such as MAE, PEF, UAE, ohmic technology and HPH, are used. Certain protocols such as HPH, UAE or MAE continue to use solvents for extraction after this pretreatment, although milder (8,27,29,31,34,37-41).

Valorization for the generation of biofuels

The generation of biofuels and biogas is a pending task in the European Union, being a concept of almost zero waste reuse. According to the European Commission, the biorefinery is one of the most attractive proposals for waste recovery, promoting sustainable economic growth (42,43).

In addition, the amount of waste that can be used as raw materials is high. Initially, this food waste was deposited in landfills where it decomposed into liquid compounds and methane. The latter is the main compound that can be used for gas production, which is why several studies have focused on the potential of tomato as a biofuel generator (12,44-46). To generate it, anaerobic digestion (AD) of the food is necessary. On the use of the raw material, different results have been obtained due to the need to establish strategies in which the digestibility of the biomass is facilitated and the surface area of action of the microorganisms is increased. Pretreatments include thermal, physical, chemical or biological (4,12,43,47).

In general, the production of biofuels through the use of extractions and AD represents an effective and feasible solution to maximize the yield of high value-added compounds such as tomatoes, in addition to helping to reduce the environmental footprint (48,49).

Method

This article consists of a narrative review of scientific articles to determine the valorization in the use of tomato food waste from cultivation to consumption.

In order to carry it out, we proceeded to search for scientific articles on the area to be treated, in this case, the valorization in the use of Solanum lycopersicum. For the development of the state of the art, the review was started on January 09, 2023 and finalized on March 29, 2023, both publications and books of interest were consulted, as well as relevant international organizations in reference to product valorization and circular economy (1,6,9).

Likewise, it was taken into account that the items had an age, except in specific cases, of 5 years, i.e. the range used was from 2018 to 2023. Exceptions regarding their age were due to historical significance. The languages of the articles included in the review are English and Spanish. And the impact factor required in the studies was a minimum of one out of five. On the other hand, among the exclusion criteria are those that do not contribute to understanding the objective of tomato food recovery, invalid studies due to poor statistical analysis, erroneous execution design, and those prior to 2018 that lack historical relevance to be included (6,9,10,14).

The databases used in the search for articles, documents and studies are listed below, in order from most to least important in terms of their use.

1. Pubmed: As keywords used for the article search, the following terms were used in English:

- Tomato valorization "Tomato valorization". A total of 78 related documents were acquired from this search. For the screening of the articles, the established inclusion criteria were taken into account, although it is true that since the purpose of this search was to find the origins of this part of science as well as the history in this regard, after this search, the bibliography of the articles was searched until the first author was found. Therefore, a total of 15 articles were selected that were useful for the literature review process.

- Valorization of Solanum Lycopersium "Solanum Lycopersium valorization" A total of 38 results were found with the search, of which 2 of them helped in the writing of the article, although in the previous search articles were found that dealt with the subject together.

- Tomato waste "Tomato waste". A total of 352 articles were obtained, of which 4 were used for the literature review.

2. ScienceDirect: As keywords, the following terms were used in English:

- Tomato valorization "Tomato valorization": Out of a total of 1278 articles, 17 were used.

- Tomato by-products "Tomato by-products": A total of 54 articles were found in the search, 4 of which were part of the study.

- Biogas from tomato "Biogas from tomato": Of the 1246 articles found, 3 were used.

3. Scielo: As keywords, the following term was used:

- Tomato by-products: Of the 4 results obtained, only 1 was used for the article.

4. Internet. A Google search was conducted on aspects of food waste, circular economy and food recovery projects. Documents belonging to official scientific associations in health and industry, such as FAO, were consulted. The keywords used in these searches were "circular economy" and "food recovery". Six publications were selected, one of which was used to define terms and to complete and verify information provided by articles and documents.

Finally, a total of 52 articles were used for the literature review.

Discussion and conclusions

The valorization of tomato as a food from which carotenoids, CF and pectin are extracted, in addition to its use for the formation of biogas, can be an important strategy for reducing food waste and transitioning to a circular economy (4,20).

In relation to the use of Solanum lycopersicum as a raw material from which to extract lycopene, 12 articles address the subject directly, as shown in Table 1. Among the results obtained, there is a common similarity, in all those that have used emerging techniques, they bet on the use of these as the main methodology to obtain a greater extraction of lycopene. Supercritical CO_2 (11,31) is presented as an emerging method that needs to be investigated, due to its possible benefits in relation to not needing to use solvents, as well as HPH (31), which does not require subsequent extractions with solvents that can affect the environment.

Among the articles assessing traditional extraction (12,21,28,29,40), two of them find higher amounts of lycopene in tomato skin (28,29), while the rest extract it from tomato branches or biomass pruning (12,40) and from tomato paste rather than pomace (21). As for the most efficient method of extraction, neither the percentage of purity nor the most effective solvent for the process is specified.

The difference in the results obtained between the studies is mainly centered on the method used and the part of the tomato valorized, with greater use of in situ tomato and tomato pomace for lycopene valorization (11,31).

Table 1. Valorization for lycopene extraction

Study	Target	Methodology	Valued portion	Parameters	Results
Almeida et al. 2021 (12)	Investigate the valorization of tomato production residues.	Traditional (organic solvents)	Broken tomatoes, green tomato and tomato branches	SPME and GC/SM of CF, β-carotene and lycopene	Higher carotenoid extraction was obtained in tomato branches
Górecka et al. 2020 (21)	To know the lycopene content in fresh and dried tomatoes and tomato pomace, as well as in tomato paste at different harvesting times	Traditional (organic solvents)	Green tomato, ripe tomato, tomato paste and tomato pomace	Liquid chromatography , measured in mg/100 g dm	Higher content in tomato paste vs. tomato pomace irrespective of harvest time
Popescu et al. 2022 (11)	Identification of natural sources, extraction efficiency and evaluation of antioxidant activity	Supercritical CO_2	Diced tomato, tomato pulp and tomato seeds	Tomato matrices, extraction methods, green solvents and operating parameters	The highest amount of lycopene was extracted from tomato pulp. At 450 bar, 70 ºC and 11 kg/h, 016.94 ± 23.95 mg lycopene/100 g extracted were obtained.
Lazzarini et al. 2022 (28)	To valorize tomato pomace, a by-product composed of skin and seeds, by extracting carotenoids, especially lycopene and β-carotene	Comparison of SC*, freeze-drying and SANT*, in addition to traditional methods: H-A* compared to 2 greens: EA-EL*,M-AL.*, EA-EL*,M-AL.*, EA-EL*,M-AL	Tomato skins, tomato seeds and tomato pomace	Extraction with ethyl acetate to measure lycopene and β-carotene in µg/g of dry sample,	Tomato skin has more lycopene. The most effective way of its removal is with the use of EA-EL together with SANT.

Añibarro-Ortega et al. 2020(40)	To know the phenolic composition and bioactive properties of the primary by-products of the tomato plant	Ethanol with Folin-Ciocalteu solution and sodium carbonate, 30 min at 40ºC.	Aerial biomass after the end of the crop cycle and pruning mass	HPLC-DAD-ESI/MS^n for identification of phenolic acids and flavonoids	Increased amount of carotenoids and antioxidants in biomass produced from pruning tissue
Pataro et al. 2018 (30)	to evaluate PEF in combination with steam blanching of tomato fruits in tomato processing, to provide, in addition to increased energy efficiency of the peeling process and improvements in carotenoid recovery	Blanching with PEF and acetone	Tomato skin	Measurement by spectrophotometry at 470nm, 645nm and 662nm	The application of the combined treatment increased carotenoid content and power (37.9 mg/100 g fresh weight of tomato peels).
Coelho et al. 2019 (8)	Optimizing the extraction of BC from tomato by-products by OH and PEF	Comparison between O_HAE and PEF with the aid of 70% ethanol	Tomato peel and tomato seeds	Amount of lycopene measured in µg/gFW	O_HAE as the best technique for lycopene extraction.
Jurić et al. 2019 (31)	Investigate the potential of HPH processing of tomato peel in water for the recovery of intracellular compounds and the possibility of making the best use of by-products from the tomato processing industry	Comparison between HPH, organic solvents and supercritical CO_2	Tomato skin	CF measured in mg GAE/L and lycopene by UV-Vis spectra analysis (pellet-ethyl lactate curve) and subsequent analysis of pellets for lycopene absorption (mg/g)	56.1% lycopene extracted by HPH and without the need for any organic solvent compared to traditional organic solvents and supercritical CO_2.
Pataro et al. 2020 (26)	Influence of PEF at different field strengths (E = 1-5 kV/cm) and energy inputs (WT = 5-10 kJ/kg) on the recovery yield of lycopene in acetone or ethyl lactate from industrial tomato peel waste.	PEF	Tomato skin	Extraction rate and antioxidant power by HPLC	Increased extraction of bioactive compounds from tomatoes
Nagarajan et al. 2020 (25)	To evaluate the potential of carotenoid-pectin complexation in tomato pomace containing carotenoids and pectin.	WIHC vs. traditional methods	Tomato pomace	Use of complexation and traditional methods measured in mg carotenoid fractions/100 g tomato pomace	Recovery was 9.43 mg carotenoid fractions/100 g tomato pomace with WIHC.

Szabo et al. 2019 (29)	To evaluate the CF and carotenoid content of tomato peels	Traditional (organic solvents)	Skin, seeds and general pruning waste on 10 different types of tomatoes	Amount of lycopene in mg β-carotene/100 g DW and CF in mg/100 g DW	The highest amount of lycopene found in tomato skin from a local tomato with 5.31 ± 0.12 mg/100 g.
Nunes et al. 2022 (32)	Using non-conventional MAE and PLE techniques to recover bioactive compounds from tomato pomace	Comparison between MAE, PLE and traditional methodologies	Tomato pomace	Amount of lycopene measured in µg lycopene/g extract	Extraction with MAE showed the highest lycopene content (59.66 µg lycopene/g extract recovery of 66.93% compared to a standard technique with acetone.
Kehili et al. 2019 (50)	Optimization of tomato skin extraction by maceration	Maceration in refined olive oil (AOR)	Tomato skins	Amount of lycopene measured in mg/kg on dry basis	99.3% of the initial lycopene content was extracted using a biomass/oil ratio of 2.5% (w/v), at 80ºC and 400rpm agitation for 45 minutes, obtaining 35mg lycopene/kg AOR

* SC: Heat drying; SANT: Non-thermal air drying; H-A: Hexane-acetone; EA-EL: Ethyl acetate-ethyl lactate; M-AL: Methanol-Lactic acid

On the other hand, 10 articles address the issue of recovery for obtaining FC. The results obtained from tomato valorization for the extraction of FC can be seen in Table 2. The largest amounts extracted have been found in the skin and pulp of tomatoes (8,29,38-40).

As for the extractive methods used, emerging methods predominate over traditional ones, with greater quantities obtained with them (31). The results suggest that the use of OHAE, HPH and MAE could be the best option for tomato valorization and CF extraction (8,31,41). In the case of phenolic compounds, one of the studies in which traditional extraction is performed, 70% methanol is cited as the best extractive method among the existing ones (34).

Table 2. Valorization for the extraction of FC

Study	Target	Methodology	Valued portion	Parameters	Results

Almeida et al. 2021 (12)	Investigate the valorization of tomato production residues.	Traditional	Broken tomatoes, green tomato and tomato branches	SPME and GC/SM of of of CF, β-carotene and lycopene.	Higher FC extraction was obtained in green and broken tomatoes (not suitable for consumption initially)
Añibarro-Ortega et al. 2020 (40)	To know the phenolic composition and bioactive properties of the primary by-products of the tomato plant	Ethanol with Folin-Ciocalteu solution and sodium carbonate, 30 min at 40ºC.	Aerial biomass after the end of the crop cycle and pruning mass	HPLC-DAD-ESI/MS^n for identification of phenolic acids and flavonoids	Increased CF in biomass produced from pruning tissues
Coelho et al. 2019 (8)	Optimizing the extraction of BC from tomato by-products by OH and PEF	O_HAE and PEF with the aid of 70% ethanol	Tomato peel and tomato seeds	Amount of lycopene measured in μg/gFW	O_HAE as the best technique for CF extraction.
Jurić et al. 2019 (31)	Investigate the potential of HPH processing of tomato peel in water for the recovery of intracellular compounds and the possibility of making the best use of by-products from the tomato processing industry	HPH, organic solvents and supercritical CO_2	Tomato skin	CF measured in mg GAE/L and lycopene by UV-Vis spectra analysis (pellet-ethyl lactate curve) and subsequent analysis of pellets for lycopene absorption (mg/g)	32.2 % more CF extracted by HPH versus organic solvents and supercritical CO_2.
Bao et al. 2020 (37)	To examine the effect of HVACP on tomato pomace microstructure and correlate it with CF extraction	HVACP (Air, He, Ar and N_2)	Tomato pomace	Creation of analysis curve with spectrophotometry and conversion to mg GAE/gdm	Higher CF extraction (10% increase) with He and N_2 plasmas.
Szabo et al. 2019 (29)	To evaluate the CF and carotenoid content of tomato peels	Traditional (organic solvents)	Skin, seeds and general pruning waste on 10 different types of tomatoes	Amount of lycopene in mg β-carotene/100 g DW and CF in mg/100 g DW	The highest amount of CF was found in the tomato skin of a commercial hybrid tomato with 155 ± 2 mg/100 g.

Ninčević et al. 2020 (34)	To seek the use of tomato peel waste for the simultaneous recovery of high-value compounds	Traditional (organic solvents)	Dried tomato peel for the extraction of aagg-pectin and phenolic compounds-pectin	Amount of FC measured in mg/100 g, in 96% ethanol and pectins in g/L	The extraction of the CF together with the pectin does not oxidize, although its extraction is lower. The best solvent for extraction is 70% ethanol.
Arab et al. 2019 (38)	Develop methods to extract compounds of high commercial value	Subcritical CO_2	Tomato leaves	Amount of CF measured in mg (GAE) g-1and of flavonoids in mg Qe g-1	The FC obtained from tomato leaves, by CO_2 extraction at high pressure and without solvents achieved substantial improvements over traditional methods (contracted with bibliography).
Solaberrieta et al. 2022 (51)	Optimizing MAE and UAE of antioxidant compounds from tomato seeds using response surface methodology.	Comparison between MAE and UAE with ethanol support	Tomato seeds	MAE and UAE extraction parameters on total phenolic content (TPC) and antioxidant activity (DPPH) responses in mg GAE g TS-1.	MAE extracts showed higher total CF values compared to UAE (1.72 ± 0.04 and 1.61 ± 0.03 mg GAE g TS-1 for MAE and UAE, respectively)
Tranfić Bakić et al. 2019 (39)	Describe MAE as an innovative technique for the isolation of polyphenols from tomato peel waste	MAE with methanol at different times and Tª (22, 55 and 90ºC) (5-10 min)	Tomato skins	Parameters of kaemferol-3-O-rutoside, p-coumaric acid and chlorogenic acid derivative for CF quantification	Time is not a significant factor in the extraction of FCs, in terms of Tª and methanol: 50% methanol 25 °C; 70% methanol 55 °C or 50% methanol 90 °C for higher extraction.

* Identification of volatile compounds by solid-phase microextraction (SPME) and gas chromatography-mass spectrometry (GC/MS)

With regard to tomato pectin extraction, the present article focuses on four studies shown in Table 3. Three of the articles (22,34,34) suggest that innovative techniques are more effective in extracting the compounds, although one of the articles (25) does not observe significant differences between traditional and WIHC in particular.

The most effective emerging techniques are UAME (36) and HPH (22). Pectin extraction is extracted in half of the articles from tomato peel (34,36) and the other half from tomato pomace (22,25). One of the reviewed studies even shows similar pectin recovery with WIHC and traditional methods (25).

Table 3. Valorization for pectin extraction

Study	Target	Methodology	Valued portion	Parameters	Results
Sengar et al. 2020 (36)	Reducing the carbon footprint by extracting pectin from tomato peel	Comparison between 5 techniques: UAE, MAE, O_HAE, UAME UAO_HE	Tomato skin	Amount of pectin in g/kg of pectin, by galacturonic acid	UAME is the best technology in terms of yield and pectin quality compared to other technologies.
Ninčević et al. 2020 (34)	To seek the use of tomato peel waste for the simultaneous recovery of high-value compounds	Traditional (organic solvents)	Dried tomato peel	Amount of FC measured in mg/100 g, in 96% ethanol and pectins in g/L	The extraction of pectin-aagg or CF-pectin helps to avoid oxidation
Pirozzi et al. 2022 (22)	To achieve cellulose isolation for the valorization of value-added compounds contained in biomass	HPH with acid hydrolysis vs. traditional extraction with acetone	Tomato pomace	Cellulose and pectin measured in mg_{GAE}/g_{DM}	HPH promoted a 9% increase in extraction. It was even extracted without the need for the solvent.
Nagarajan et al. 2020 (25)	To evaluate the potential of carotenoid-pectin complexation in tomato pomace containing carotenoids and pectin.	WIHC vs. traditional methods	Tomato pomace	Use of complexation and traditional methods measured in mg carotenoid fractions/100 g tomato pomace	Recovery was of traditional pectin-carotenoids vs. WIHC is similar

Finally, the valorization for obtaining biofuels, for the article seven studies shown in Table 4 were taken into account. Most of the studies made use of tomato pomace (45,52) or a mixture of tomato and other compounds such as animal manure and other food residues (7,46,47). Of the seven studies, two of them performed prior extractions for the valorization of lycopene and other bioactive compounds (12,44).

Among the mixtures of compounds for biogas formation, olive pumice (OP), sheep manure (SM), corn stover and dairy manure give the highest biogas production (7.46). Among the emerging methodologies studied, UAE is particularly relevant (47.52).

Table 4. Valorization for the formation of biofuels

Study	Target	Methodology	Valued portion	Parameters	Results
Almeida et al. 2021 (12)	Extraction for biogas formation after the valorization of other bioactive compounds	Traditional	Broken tomatoes, green tomato and tomato branches	SPME and GC/SM of CF, β-carotene and lycopene	A higher methanol extraction was obtained in green and broken tomatoes, with a final amount contributed of 232-285 mL CH4/g
Tabrika et al. 2021 (7)	Direct DA (without prior valorization of other compounds)	Traditional	Tomato mixture with: OP, SM, chicken manure (CM) and sawdust.	Measurements of humic acid-type carbon (HAC) and fulvic acid-type carbon (FAC) concentrations	SM and OP are the most suitable raw materials for tomato waste composting.
Scaglia et al. 2020 (44)	Pre-valorization of lycopene by supercritical CO_2 and subsequent DA	Supercritical CO_2	Tomato peel and tomato seeds	Supercritical CO2 extraction technology in combination with anaerobic digestion, in % biodegradability	Supercritical CO_2 acts positively for the prior degradation of the fiber and its subsequent DA resulting in energy (better than corn-currently used to give biogas)
Hijosa-Valsero et al. 2019 (45)	Direct valorization by twelve different strains of bacteria with acetone-butanol-ethanol-ethanol-isopropanol fermentation (ABEI)	Traditional	Tomato pomace	Butanol and isopropanol measurements in g/L	*Kluyveromyces marxianus*, *Saccharomyces cerevisiae Ethanol Red®*, *S. cerevisiae Hercules* and *Lachancea thermotolerans* produced 20.1-21.7 g/L ethanol. According to these results, tomato pomace could be an interesting feedstock for ABEI biorefineries.
Mahmoodi-eshkaftaki et al. 2022 (47)	DA together with an AEU pretreatment at different powers and times	UAE	Tomato waste and cow manure	Measurements of hydrogen and methane, based on mg/g generated from volatile solids, carbohydrates and total solids	The UAE of 197.21 W, 21.47 min for mixtures with high amounts of tomato residues (>90 %) led to produce Bio-H_2 > 18 %vol and Bio-CH_4 > 2 %vol.

Girotto et al. 2021 (52)	Direct DA with UAE pretreatment, without extraction of biocompounds	UAE	Tomato pomace	Methane production in MJ/kg solid	The increase in methane production was not high enough to offset UAE's electricity needs
Li et al. 2020 (46)	Direct DA (without prior valorization of other compounds)	Traditional	Tomato peel together with corn or dairy manure	Amount of methane in L/kg of solid weight	Net energy production was achieved with the mixture of 24% corn stover, 36% dairy manure and 40% tomato waste: formation 379.1 L/kg $VS_{Methane\ feed}$

The general objective of the article is to determine whether there are significant differences between the different recovery methods for the use of tomato by-products, and it can be concluded that the greatest difference is found in the traditional methods compared to the emerging ones. Most of the traditional methods are still the most economically profitable, but this is not the case for the more environmentally friendly part, as they tend to generate larger amounts of environmentally harmful compounds. In addition, newer methodologies generally have the ability to increase the extraction of bioactive compounds from the food.

Among the emerging methodologies, PEF, MAE, UAE and supercritical CO2 as a necessary pretreatment prior to extraction stand out. These are the most studied of all the processes currently in existence. The main reasons are higher economic profitability and better extraction of target molecules. Among all the methods of utilization of by-products, it is necessary to emphasize the differences that exist not only in the utilization of the by-products, but also in the part valorized and in the measures used for the quantification of the by-product obtained, which makes it difficult to compare the studies.

As discussed throughout the paper, tomato by-products have many interesting and sustainable applications. The fact that tomato by-products contain high levels of anti-inflammatory and antioxidant compounds shows potential for further research. To focus on new proposals with the objective of achieving the optimization of this food. It is important to note that there are not yet many studies available that demonstrate the effectiveness of these innovative applications in practice.

To date, according to the studies, there is no extraction method that is more economically viable than synthetic production or traditional extraction, although according to the conclusions reached in them, this is closer to being achieved.

Acknowledgments

To my parents and my sister, for being an example of self-improvement and daily effort.

Conflict of interest

There are no relevant conflicts of interest in this article.

References

1. FAO, editor. Moving forward on food loss and waste reduction. Rome: Food and Agriculture Organization of the United Nations; 2019. 156 p. (The state of food and agriculture).
2. Leong YK, Chang JS. Valorization of fruit wastes for circular bioeconomy: Current advances, challenges, and opportunities. Bioresour Technol. September 1, 2022;359:127459.
3. Trombino S, Cassano R, Procopio D, Di Gioia ML, Barone E. Valorization of Tomato Waste as a Source of Carotenoids. Mol Basel Switz. aug 20, 2021;26(16):5062.
4. Eslami E, Carpentieri S, Pataro G, Ferrari G. A Comprehensive Overview of Tomato Processing By-Product Valorization by Conventional Methods versus Emerging Technologies. Foods Basel Switz. dec 29, 2022;12(1):166.
5. Cámara Hurtado M. Productos, extractos y subproductos del tomate como nuevos ingredientes alimentarios [Internet]. [cited Mar 7, 2023]. Retrieved from: https://www.ucm.es/otri/complutransfer-productos-extractos-y-subproductos-del-tomate-como-nuevos-ingredientes-alimentarios
6. Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). España Circular 2030 [Internet]. Catálogo de Publicaciones de la Administración General del Estado; 2023. Retrieved from: https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/espanacircular2030_def1_tcm30-509532_mod_tcm30-509532.pdf
7. Tabrika I, Mayad EH, Furze JN, Zaafrani M, Azim K. Optimization of tomato waste composting with integration of organic feedstock. Environ Sci Pollut Res Int. Dec. 2021;28(45):64140-9.
8. Coelho M, Pereira R, Rodrigues AS, Teixeira JA, Pintado ME. Extraction of tomato by-products' bioactive compounds using ohmic technology. Food Bioprod Process. September 1, 2019;117:329-39.
9. Esparza I, Jiménez-Moreno N, Bimbela F, Ancín-Azpilicueta C, Gandía LM. Fruit and vegetable waste management: Conventional and emerging approaches. J Environ Manage. July 1, 2020;265:110510.
10. Coelho MC, Rodrigues AS, Teixeira JA, Pintado ME. Integral valorisation of tomato by-products towards bioactive compounds recovery: Human health benefits. Food Chem. June 1, 2023;410:135319.
11. Popescu M, Iancu P, Plesu V, Todasca MC, Isopencu GO, Bildea CS. Valuable Natural Antioxidant Products Recovered from Tomatoes by Green Extraction. Mol Basel Switz. June 29, 2022;27(13):4191.
12. Almeida PV, Rodrigues RP, Gaspar MC, Braga MEM, Quina MJ. Integrated management of residues from tomato production: Recovery of value-added compounds and biogas production in the biorefinery context. J Environ Manage. dec. 1, 2021;299:113505.

13. Liadakis G, Katsouli M, Chanioti S, Giannou V, Tzia C. Identification, quantification, and characterization of tomato processing by-products. In: Jeguirim M, Zorpas A, editors. Tomato Processing by-Products [Internet]. Academic Press; 2022 [cited 2023 March 30]. p. 1-32. Available from: https://www.sciencedirect.com/science/article/pii/B9780128228661000041
14. Cabo Domínguez CM, Rodríguez Moratinos AB, Garrido Álvarez M. Valorización de subproductos de la agroindustria para una economía verde y circular. Universidad de Extremadura [Internet]. 2020; Retrieved from: https://dehesa.unex.es/bitstream/10662/11732/1/978-84-09-26056-0.pdf
15. Gurri A, Aguiló-Aguayo I, Abadias M, Echeverria G, Bobo G, Vilanova L, et al. Valorización de los desperdicios de la producción y procesado de tomate, aceituna, patata y cereales. Interempresas [Internet]. April 14, 2021 [cited February 25, 2023]; Retrieved from: https://www.interempresas.net/Horticola/Articulos/315961-Valorizacion-desperdicios-produccion-procesado-tomate-aceituna-patata-cereales.html
16. Saba B, Bharathidasan AK, Ezeji TC, Cornish K. Characterization and potential valorization of industrial food processing wastes. Sci Total Environ. April 10, 2023;868:161550.
17. Rodríguez-Valdés A, Florido-Bacallao M, Dueñas-Hurtado F, Muñoz-Calvo LJ, Hanson P, Álvarez-Gil M. MORFOAGRONOMIC CHARACTERIZATION IN TOMATO (Solanum lycopersicum L.) LINES WITH RESISTANCE TO BEGOMOVIRUS. Cultiv Trop. 2017;38(2):70-9.
18. Laranjeira T, Costa A, Faria-Silva C, Ribeiro D, de Oliveira JMPF, Simões S, et al. Sustainable Valorization of Tomato By-Products to Obtain Bioactive Compounds: Their Potential in Inflammation and Cancer Management. Mol Basel Switz. mar 4, 2022;27(5):1701.
19. Ibrahim M, Labaki M. Extraction and formulation of valuable components from tomato processing by-products. In: Jeguirim M, Zorpas A, editors. Tomato Processing by-Products [Internet]. Academic Press; 2022 [cited March 30, 2023]. p. 77-116. Available at: https://www.sciencedirect.com/science/article/pii/B9780128228661000090
20. Szabo K, Cătoi AF, Vodnar DC. Bioactive Compounds Extracted from Tomato Processing by-Products as a Source of Valuable Nutrients. Plant Foods Hum Nutr Dordr Neth. Dec 2018;73(4):268-77.
21. Górecka D, Wawrzyniak A, Jędrusek-Golińska A, Dziedzic K, Hamułka J, Kowalczewski PŁ, et al. Lycopene in tomatoes and tomato products. Open Chem. 2020;18(1):752.
22. Pirozzi A, Ferrari G, Donsì F. Cellulose Isolation from Tomato Pomace Pretreated by High-Pressure Homogenization. Foods Basel Switz. jan 19, 2022;11(3):266.
23. Awasthi MK, Harirchi S, Sar T, Vs V, Rajendran K, Gomez-Garcia R, et al. Myco-biorefinery approaches for food waste valorization: Present status and future prospects. Bioresour Technol. September 1, 2022;360:127592.
24. Soto MDS, Zorpas AA, Pedreño JN, Lucas IG. Vermicomposting of tomato wastes. In: Jeguirim M, Zorpas A, editors. Tomato Processing by-Products [Internet]. Academic Press; 2022 [cited March 30, 2023]. p. 201-30. Available at: https://www.sciencedirect.com/science/article/pii/B9780128228661000107
25. Nagarajan J, Pui Kay H, Krishnamurthy NP, Ramakrishnan NR, Aldawoud TMS, Galanakis CM, et al. Extraction of Carotenoids from Tomato Pomace via Water-Induced Hydrocolloidal Complexation. Biomolecules. july 9, 2020;10(7):1019.

26. Pataro G, Carullo D, Falcone M, Ferrari G. Recovery of lycopene from industrially derived tomato processing by-products by pulsed electric fields-assisted extraction. Innov Food Sci Emerg Technol. July 1, 2020;63:102369.
27. Andreou V, Dimopoulos G, Dermesonlouoglou E, Taoukis P. Application of pulsed electric fields to improve product yield and waste valorization in industrial tomato processing. J Food Eng. April 1, 2020;270:109778.
28. Lazzarini C, Casadei E, Valli E, Tura M, Ragni L, Bendini A, et al. Sustainable Drying and Green Deep Eutectic Extraction of Carotenoids from Tomato Pomace. Foods Basel Switz. jan 30, 2022;11(3):405.
29. Szabo K, Diaconeasa Z, Cătoi AF, Vodnar DC. Screening of Ten Tomato Varieties Processing Waste for Bioactive Components and Their Related Antioxidant and Antimicrobial Activities. Antioxidants. Aug 2019;8(8):292.
30. Pataro G, Carullo D, Bakar Siddique MA, Falcone M, Donsì F, Ferrari G. Improved extractability of carotenoids from tomato peels as side benefits of PEF treatment of tomato fruit for more energy-efficient steam-assisted peeling. J Food Eng. September 1, 2018;233:65-73.
31. Jurić S, Ferrari G, Velikov KP, Donsì F. High-pressure homogenization treatment to recover bioactive compounds from tomato peels. J Food Eng. Dec 1, 2019;262:170-80.
32. Nunes Chada PS, Santos PH, Rodrigues LGG, Goulart GAS, Azevedo dos Santos JD, Maraschin M, et al. Non-conventional techniques for the extraction of antioxidant compounds and lycopene from industrial tomato pomace (Solanum lycopersicum L.) using spouted bed drying as a pre-treatment. Food Chem X. mar 30, 2022;13:100237.
33. Petrotos K, Gerasopoulos K. Sustainable use of tomato pomace for the production of high added value food, feed, and nutraceutical products. In: Iulianelli A, Cassano A, Conidi C, Petrotos K, editors. Membrane Engineering in the Circular Economy [Internet]. Elsevier; 2022 [cited Feb. 6, 2023]. p. 315-42. Available at: https://www.sciencedirect.com/science/article/pii/B9780323852531000149
34. Ninčević Grassino A, Djaković S, Bosiljkov T, Halambek J, Zorić Z, Dragović-Uzelac V, et al. Valorisation of Tomato Peel Waste as a Sustainable Source for Pectin, Polyphenols and Fatty Acids Recovery Using Sequential Extraction. Waste Biomass Valorization. September 1, 2020;11(9):4593-611.
35. Madia VN, De Vita D, Ialongo D, Tudino V, De Leo A, Scipione L, et al. Recent Advances in Recovery of Lycopene from Tomato Waste: A Potent Antioxidant with Endless Benefits. Mol Basel Switz. July 26, 2021;26(15):4495.
36. Sengar AS, Rawson A, Muthiah M, Kalakandan SK. Comparison of different ultrasound assisted extraction techniques for pectin from tomato processing waste. Ultrason Sonochem. march 1, 2020;61:104812.
37. Bao Y, Reddivari L, Huang JY. Development of cold plasma pretreatment for improving phenolics extractability from tomato pomace. Innov Food Sci Emerg Technol. oct 1, 2020;65:102445.
38. Arab M, Bahramian B, Schindeler A, Valtchev P, Dehghani F, McConchie R. Extraction of phytochemicals from tomato leaf waste using subcritical carbon dioxide. Innov Food Sci Emerg Technol. oct 1, 2019;57:102204.
39. Bakić MT, Pedisić S, Zorić Z, Dragović-Uzelac V, Grassino AN. Effect of Microwave-Assisted Extraction on Polyphenols Recovery from Tomato Peel Waste. Acta Chim Slov. june 13, 2019;66(2):367-77.
40. Añibarro-Ortega M, Pinela J, Ćirić A, Martins V, Rocha F, Soković MD, et al. Valorisation of table tomato crop by-products: Phenolic profiles and in vitro

antioxidant and antimicrobial activities. Food Bioprod Process. nov 1, 2020;124:307-19.
41. Solaberrieta I, Mellinas C, Jiménez A, Garrigós MC. Recovery of Antioxidants from Tomato Seed Industrial Wastes by Microwave-Assisted and Ultrasound-Assisted Extraction. Foods Basel Switz. oct 3, 2022;11(19):3068.
42. Selvaggi R, Valenti F, Pecorino B, Porto SMC. Assessment of Tomato Peels Suitable for Producing Biomethane within the Context of Circular Economy: A GIS-Based Model Analysis. Sustainability. January 2021;13(10):5559.
43. Mishra A, Kumar M, Bolan NS, Kapley A, Kumar R, Singh L. Multidimensional approaches of biogas production and up-gradation: Opportunities and challenges. Bioresour Technol. october 1, 2021;338:125514.
44. Scaglia B, D'Incecco P, Squillace P, Dell'Orto M, De Nisi P, Pellegrino L, et al. Development of a tomato pomace biorefinery based on a CO2-supercritical extraction process for the production of a high value lycopene product, bioenergy and digestate. J Clean Prod. january 10, 2020;243:118650.
45. Hijosa-Valsero M, Garita-Cambronero J, Paniagua-García AI, Díez-Antolínez R. Tomato Waste from Processing Industries as a Feedstock for Biofuel Production. BioEnergy Res. dec 1, 2019;12(4):1000-11.
46. Li Y, Xu F, Li Y, Lu J, Li S, Shah A, et al. Reactor performance and energy analysis of solid state anaerobic co-digestion of dairy manure with corn stover and tomato residues. Waste Manag. March 1, 2018;73:130-9.
47. Mahmoodi-Eshkaftaki M, Ghani A. An efficient process for improvement of biohydrogen and biomethane production from tomato waste: Inhibitory effects of ultrasonic pretreatment. Fuel. nov 15, 2022;328:125273.
48. Szilágyi Á, Bodor A, Tolvai N, Kovács KL, Bodai L, Wirth R, et al. A comparative analysis of biogas production from tomato bio-waste in mesophilic batch and continuous anaerobic digestion systems. PLOS ONE. mar 17, 2021;16(3):e0248654.
49. Azabou S, Louati I, Ben Taheur F, Nasri M, Mechichi T. Towards sustainable management of tomato pomace through the recovery of valuable compounds and sequential production of low-cost biosorbent. Environ Sci Pollut Res Int. November 2020;27(31):39402-12.
50. Kehili M, Sayadi S, Frikha F, Zammel A, Allouche N. Optimization of lycopene extraction from tomato peels industrial by-product using maceration in refined olive oil. Food Bioprod Process. september 1, 2019;117:321-8.
51. Solaberrieta I, Mellinas C, Jiménez A, Garrigós MC. Recovery of Antioxidants from Tomato Seed Industrial Wastes by Microwave-Assisted and Ultrasound-Assisted Extraction. Foods. January 2022;11(19):3068.
52. Girotto F, Lavagnolo MC, Acar G, Piazza L. Bio-methane production from tomato pomace: preliminary evaluation of process intensification through ultrasound pre-treatment. J Mater Cycles Waste Manag. January 1, 2021;23(1):416-22.