WORKSHOP - FROM WASTE TO WEALTH: EXPLORING THE POWER OF AGRO-INDUSTRIAL WASTE

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ABSTRACT: The bioeconomy aims to close the material resource loop with virtually no net waste generation converting bio-residues into valuable products. Bio-waste results a key stream with a high potential for contributing to a more circular economy. The growing interest on a sustainable management and optimal resource utilization leads the attention toward different biomasses as potential sources for producing environmentally friendly products. In recent years, the management of biowaste and agricultural solid waste has become a crucial issue due to the increasing environmental problem. Fruit and vegetable production and processing generate biomass losses which are inevitable and may pose serious environmental risk if not properly treated but also mean the loss of valuable nutrients. In fact, bio- and agri-food waste are sources rich of nutrients and the utilization of these residues as feedstock for fertilizers production can provide a sustainable solution for nutrient recovery.
The workshop's presentations provide a hint to discuss and analyze the opportunities and the limits related to biomass valorization in terms of energy, organic substances, nutrients and other molecules recovery minimizing environmental impact. The paper summarizes the main objectives and results of works conducted by three research centers, the Bioeconomy Unit of Fondazione Edmund Mach (FEM), the Green Processes Engineering group of University of Trento and the Viticulture and Enology Research Center of CREA. The projects showed potential management solutions of biowaste and agro-industrial waste combining waste utilization with the production of value-added products, including organic fertilizers, in line with the principles of the circular bioeconomy and the most recent European strategies.

Keywords: bioeconomy, bio-waste treatment processes, nutrients recovery, fertilizers.

1. FROM APPLE POMACE TO SOIL AMENDMENTS: THE "SMS GREEN" PROJECT

1.1. Introduction

Apple (Malus domestica) is one of the most consumed fruits worldwide. "Trentino" is the Italian region that represents one important growing area of high-quality apples throughout Europe. The apple not marketable are destined for juice extraction and snacks production, generating a lignocellulosic by-product called apple pomace (AP). The apple processing residues are about 25-30% of the initial fresh apple mass depending on variety and processing technology. The large amount, together with the high perishability due to the high water and the easily fermentable sugars content, make AP's management and destination important issues to be resolved by processing industry. AP is a heterogeneous mixture that generally contains apple peel, seeds, core, stems and pulp and is composed of dietary fibers (cellulose, hemicellulos, lignin, β-glucans, gums and pectin), easily fermentable sugars, minerals, vitamins, lipids, phenolics, proteins, carotenoids and tri-terpenoids. In view of its variable composition and abundance, apple pomace might represent a suitable substrate to be included in biorefining practice. Valorization pathways of AP to energy and amendment production can be promising options and part of the circular economy.

The experimental activities of the "SMS Green" project aimed to valorize the apple pomace and, at the same time, to obtain products of quality for the management of soil fertility of mountain orchards. Alongside composting, widely known for amendments production, anaerobic digestion (AD) was considered to exploit these residues in co-digestion with livestock manures locally present. The AP treatment's choices aimed to combine the use of locally agro-industrial residues with the production of value-added products, such as organic fertilizers, to meet the organic substance and nutrient needs of the orchards located in the province.

The project, started in 2022 and currently in progress, is co-financed by the Rural Development Plan of the Provincia Autonoma of Trento and by the FEASR 2014-2020 as part of Operation 16.1.1. (European Innovation Partnerships). The coordinator is Co.Di.Pr.A. (Consorzio Difesa Produttori Agricoli); the partners are Consorzio Melinda Snc, Agriduemila Srl and Fondazione Edmund Mach (FEM) as technical-scientific referent.

1.2. Composition-based potential of apple pomace valorization

To exploit agronomically AP, it was characterized determining the content of total solids (TS), volatile substance (VS), pH, electrical conductivity (EC), total nitrogen, organic carbon, phosphorus and potassium. The main micronutrients such as Cu and Zn and heavy metals were also quantified, in accordance with Italian Law 75/2010 for composted soil improvers.

Given the lignocellulosic character, the fractionation of dietary fibers into cellulose, hemicellulose and lignin was determined resulting in 33.9% of the dry matter of lignocellulosic fiber with a prevalence of lignin. To evaluate the degradability of the matrices via anerobic digestion for energy recovery, the BioMethane Potential (BMP) was determined. The specific production of methane resulted of interest and equal to 314 Nm^3CH_4/tVS, placing in the middle of 250-400 Nm^3CH_4/tVS range of vegetable residues' BMPs.

From the characterization of AP, the optimal moisture (72.26%), VS content (98.37%VS), %C (67.2%VS) in the biomass and the obtained BMP result demonstrate that AP may be used as valuable co-substrates in composting and biogas production.

1.3. Anaerobic co-digestion process

A semi-continuous anaerobic test was carried out for 65 days using a pilot reactor consisting of 1.8 m^3 volume, in wet (TS<10%) and mesophilic (42°C) conditions. AP was co-digested with livestock manure varying the operating conditions regarding the following parameters:

- organic loading rate (OLR): (a) 1.2 $gVSL^{-1}d^{-1}$, (b) 2 $gVSL^{-1}d^{-1}$, (c) 3.5 $gVSL^{-1}d^{-1}$;
- hydraulic retention time (HRT) from 76 to 51 days, up to 30 days;
- increasing % AP on feeding total weight, up to a maximum quantity of 30% of co-fermentants and 70% of manure according to the local restriction stated for biogas plants in agricultural areas (Article 114, "Legge Provinciale per il governo del territorio" of 2015).

This acclimation served to adapt the inoculum to the addition of the co-fermentant and to evaluate the co-digestion effects of the apple pomace in terms of volatile fatty acids accumulation and inhibition of the process. The monitoring of pH, Total Volatile Fatty Acids (VFA) and Total Alkalinity (TA) ratio (VFA/TA), revealed stable conditions of the anaerobic digestion process indicating none VFA accumulation in the reactor (pH=8.4; VFA/TA<0.4). The evaluation of the efficiency of biological processes was also determined through the degree of degradation of volatile solids. In the hypothesis of the highest AP loading rate, values of 62% VS removal are achieved which corresponded a specific daily biomethane production equal to 0.14 $NLCH_4gVS^{-1}d^{-1}$. Better performances could be obtained by testing higher AP addition percentages. In fact, the feeding substrate characteristics influence highly the anaerobic co-digestion process. As previously explained, the choice was dictated by the conditions permitted by the legislation in force, in the hypothesis of AP treatment in locally biogas plants. Another aspect to take in account regards the lignocellulosic structure of AP: the hydrolysis phase could act as rate-limiting step. In fact, the biomass recalcitrance could protect AP from degradation by microorganisms and enzymes resulting in a lower monosaccharide and, consequently, methane content. Pretreatment methods could improve the bio-methane production decomposing the complex substrate into easily digestible components to enhance the anaerobic digestion efficiency. Further, apple waste could be treated as the sole feedstocks in a dedicated anaerobic digestion plant; however, the digestion process could fail without the addition of external nutrients and buffering agents. Co-digestion with substrate having high alkalinity like cow manure represent an effective treatment of readily biodegradable materials, characterized of high carbon content resulting in a more balanced C/N ratio.

The solid fraction of digestate was separated and characterized in view of obtaining an amendment for apple orchard fertilization. The total nitrogen, carbon, phosphorous and humic and fulvic acids were comparable to nutrients' content of solid digestate sampled in livestock anaerobic digestion plants (FEM data). The results obtained from the characterization study proved that the developed anaerobic digestion process could produce a satisfactory finished product for orchard fertilization.

1.4. Composting

Similarly to AD, composting lead to the production of a solid product, i.e. compost, used as a fertilizer. The complex community of bacteria, the proper parameters for optimal microbial growth and the proper substrate work jointly for the biodegradation of organic matter. Wet AP can directly be supplemented to compost without any specific pre-treatment (i.e. drying). Because of the rich content of carbohydrates, organic acids and other substances in favor of the growth of microorganisms, AP is suitable for composting. Furthermore, the addition of AP is not only a supplement of substrates but also a potential way to adjust C/N ratio and pH that represents important parameters to monitor the evolution of the composting process.

AP was aerobically treated in the composting-pilot plant located at FEM homogenizing AP, lignocellulosic material (LM) and cow manure (CM) to form open-composting windrows of $4m^3$. The mix was prepared to guarantee density, dry matter content and C/N values to optimize microbial activity. The stoichiometric quantity of oxygen was furnished through forced aeration system to longitudinal composting piles.

Initially, the temperature increased progressively until the thermophilic regime thanks to the energy generated from oxidation reactions catalyzed by microorganisms of easily degradable organic fraction (carbohydrates and hemicelluloses: sugars, organic acids, amino acids). The most rapid increase in temperature, up to 55-60°C, occurred in the 24-48 hours following the composting windrows set up. During the maturation phase higher temperatures (>60°C) necessary for the sanitation of matrices were reached. The good porosity, nitrogen content and the presence of easily degradable matrices (AP) facilitated an intense bio-oxidative process, which caused water evaporation losses particularly during the intensive phase. It was necessary to add external water to maintain humidity values between 40 – 60%, compatible with microbial activity.

The dynamic respiration index (IR_{24}, $mgO_2kg_{VS}^{-1}h^{-1}$) measured at starting time (T0), at the end of the intensive phase (T30) and on the finished compost (T90) showed that the intense degradation activity occurs within 30 days and the degradation process is almost completely exhausted reaching stable conditions: $IR_{24,T0}$= 2185 $mgO_2kg_{VS}^{-1}h^{-1}$, $IR_{24,T30}$=332 $mgO_2kg_{VS}^{-1}h^{-1}$, $IR_{24,T90}$=310 $mgO_2kg_{VS}^{-1}h^{-1}$. The total organic carbon (TOC), nitrogen and phosphorous values obtained for the end-product characterization complies with the standard TOC, N, P values for compost.

1.5. Conclusions

The results showed that AP is a suitable source of substrate for biogas, digestate and compost production. The valorization of apple pomace to produce amendments to be used as soil improvers in fruit orchards may represent a viable strategy to reduce the large volume of this by-product. The possibility to process AP, even in local biogas plants, would avoid high transportation costs, cost- and energy-intensive drying steps for preservation favoring at-short distance utilization. In addition, the use of these products can lead to better managing of the soil organic matter in mountain orchards, creating a valuable and sustainable chain at the local level according to the Bioeconomy and Circular Economy European policies. The utilization of organic residues as feedstock, digestate and compost as fertilizers and biogas to produce bio-based energy and/or biogas upgrading with purification of CO_2 from a useless waste product to, for example, a high purity gas for the food and beverage industry, closes the CO_2 loop and plays potentially an important role in the circular bio-economy transition.

The project is now in progress and the future studies will concern the evaluation of the soil improvers effects on the microbial communities and on the dynamics of nutrients in amended soils, to better understand the benefits of AP-composted and digested as valid substitutes of synthetic fertilizers.

2. PRODUCTION OF BIOSTIMULANTS (HUMIC ACIDS) FROM COMPOST AND EFFECTS ON SOIL RIZOSPHERE AND HORTICULTURAL CROPS.

2.1. Introduction

This study is part of the project PERCIVAL (ARS01_00869) supported by the Italian Ministry of University and Research (MUR) and the PON FESR grants. PERCIVAL is aimed at integrate the skills of research institutions and companies with the need of industry leaders of the agro-industrial sector and related industrial sectors with a core business in the field of agro-medicine, nutraceutical and textiles.

The project consortium, distributed among all Italy, is involved in the development of innovative processes for pretreatment, extraction/separation and subsequent valorization, using a biorefinery cascade approach to obtain bioactive compounds for the cosmetic, nutraceutical and agronomic sectors, chemicals (e.g. PLA), and materials (high-tech fibers from lignin). In the perspective of a circular bioeconomy based on “Zero Waste” processes, residues/by-products will be converted into energy vectors (e.g. biomethane) and agricultural products (e.g. soil improver and biostimulants). Lastly, it will be evaluated the economic and environmental sustainability of the identified chain and elaborated some business case for the obtained products.

One of the FEM’s tasks concerns the production and testing of biostimulants from compost with the technical support of ACEA Pinerolese SpA. The study is aimed at finalizing the production of humic acids extract from renewable organic sources (as compost and digestate) and to increase the knowledge about the "way of action" of the biostimulant products applied to soil.

Biostimulants cannot be defined as fertilizers because they do not provide nutrients directly to plants. At the same time, they do not directly control crop pests, rather they facilitate the uptake of existing and applied nutrients, resistance to abiotic stress such as salinity or drought and contribute to sustainable, high-output low input crop production (Canellas et al., 2015; Hazra et el., 2020).

The production of biostimulants from composted biowaste is under study to assess the possibility to obtain natural humic compounds with a high added value to use in agriculture/horticulture. They can be used as sustainable and efficient plant biostimulants in alternatives to the commercial products based on fossil sources as the Leonhardite (Montoneri et al., 2022).

2.2 Production of humic acids

Three different composts are under study: 1) the solid fraction of compost after anaerobic digestion of the organic fraction of municipal solid waste (OFMSW); 2) OFMSW compost; 3) compost from agri-food processing waste. All the composts comply with the Italian law n° 75/2010, are classified as mixed composted amendment (ACM) and are freely marketable in agriculture.

The extraction was carried out in a pilot plant in batch conditions, by mixing 250 liters of water, 30 kg compost with size < 7 mm, and 4 kg KOH for 2 hours at 90°C and environmental pressure. After solid-liquid separation two fractions can be distinguished: the liquid one which contains the humic compounds and the residual solid fraction (mainly lignin).

The analytical characterization of the liquid fraction showed a pH value ranging from 9 to 11 for the three extracts, a very high conductivity (CE from 6000 to 10000 µS/cm), total solids (TS) between 2 and 6%, and volatile solids (VS) about 50% on dry matter. The humification rate, ranging from 24-26% for the three extracts, is given by the ratio of Organic Carbon to Total Carbon and it is strictly dependent on the feedstock used, the time, and the conditions of the hydrolysis reaction. The stability of the extracts over time was verified by repeated measurements of pH and CES before the application in the greenhouse on lettuce and tomato plants. In parallel phytotoxicity tests on Lepidium sativum were carried out to verify the dose-response effects.

2.3 Next steps

The work is now in progress and more steps are planned to assess the properties of the tested products and to better understand the biostimulation process. For this reason, the analysis of rhizosphere microbial community and the transcriptomic analysis of leaves are to identify the gene expression profile during biostimulation.

2.5 Acknowledgements

This activity is part of the national project PERCIVAL (ARS01_00869) supported by the Italian Ministry of University and Research (MUR) and the PON FESR grants. We acknowledge ACEA Pinerolese SpA (TO) for the cooperation in the extraction phase made possible at their pilot plant.

3. "RUSTICA" PROJECT: DEMONSTRATION OF CIRCULAR BIO-BASED FERTILISERS AND IMPLEMENTATION OF OPTIMIZED FERTILIZERS STRATEGIES AND VALUE CHAINS IN RURAL COMMUNITIES.

3.1. Introduction

The overall objective of the RUSTICA project is to provide a technical solution to convert organic residues from the fruit and vegetable sector into novel bio-based fertilizers (BBF) of high quality that address the needs of modern (organic) agriculture. The conversion of fruit and vegetable wastes into fertilizers allows the recovery of nutrients and organic matter with benefits not only for the farmers, but also for the environment and foster the evolution towards a sustainable and circular fertilizer management closing the nutrient cycles within and between regions.

The objective of the project has been sought through a transdisciplinary multi-actor approach that guaranteed the implementation potential of the technologies in the agrifood chain, and lead to sound business models. Several non-technical aspects (environmental and social LCA, legal framework, expected market developments…) have been evaluated in four European regions and one region in Colombia. Stakeholder involvement at each step guaranteed the development of marketable end products for the fruit and vegetable sector, with a high replication potential to other agricultural sectors.

3.2. Technology optimization

The technical solution is based on five conversion processes (carboxylic acid platform, CAP; microbial biomass production; electrodialysis; insect breeding and biochar production) which can be combined depending on the available waste streams and integrated with state-of-the-art technologies such as composting.

The processes have been identified to be applied to different fraction of the organic residues. The easily degradable biowaste fractions was hydrolyzed into building blocks (carboxylic acids and nutrients) in a carboxylic acid platform. These building blocks were further converted to microbial biomass in an aerobic production reactor. Alternatively, the nutrients were separated from the organic acids using electrodialysis which yield several mineral concentrates (in this scenario, the carboxylic acids were valorized in other biorefinery processes outside the RUSTICA scope). More recalcitrant biowaste (or remaining biowaste from the CAP) were converted by insects to insect biomass and frass. The remaining resistant lignin-rich biowaste has undergone a pyrolysis process (thermochemical conversion in the absence of oxygen) to produce biochar.

Each technology was first validated and optimized in a laboratory environment, building on already available knowledge and producing smaller amounts of fertilizer ingredients after which the processes were integrated and scaled up to TRL7 in two pilot demonstrators (France and Spain). The pilots allowed a further optimization of the fertilizers and the production of larger amounts of fertilizer ingredients for field trials.

3.3. Fertilizers characterization and validation

The end products of the novel technologies produced at laboratory scale were assessed by chemical characterization and laboratory soil incubation trials for their potential as fertilizers and for their impact on soil ecosystem and the environment.

Results showed that such end products can be applied separately to the soil to fulfil specific purposes. For instance, microbial and insect biomass are a good source of easily available N and provide significant amounts of readily available substrate that can fuel microbial activity. On the opposite side, with respect to the impact on soil functioning, is biochar. Biochar is very stable which suggests that the main purpose for its soil application is the buildup of soil organic C (SOC) stocks and the fostering of soil C sequestration. Insect frass shows an intermediate behavior between insect and microbial biomass from one side and biochar from the other side for that concerns the impact on soil functioning.

Therefore, the end products of RUSTICA technologies can be considered as effective fertilizers with peculiar properties that can be utilized to achieve specific agronomic and/or environmental targets. Nevertheless, a more proficient and effective way is to utilize them as building blocks to formulate fertilizer blends. In this way, it is possible to take advantage of the specific properties of each building block and to reduce their possible adverse effects. Utilizing building blocks in a blend is a way to optimize their potential and to obtain a fertilizer that can benefice of the different properties exerted by each blend constituent as a function of its decomposition rate in soil. Consequently, prototypes of blends were designed taking in consideration the wishes expressed by regional stakeholders regarding the properties of new RUSTICA fertilizers and the characteristics of each building block.

The blends' prototypes were evaluated at laboratory and pilot scale with a series of trials that were useful to refine and achieve the desired properties of the blends. Such analysis showed that biochar was the building block which amount has the stronger impact in determining blend properties. Consequently, reducing the share of biochar and increasing the content of more degradable building blocks, such as insect and microbial biomass, resulted in blends with an increased capacity to provide nutrients and improve the content and activity of microbial pool, while retaining the capacity to increase SOC stocks and foster soil C sequestration. Results also showed that there was a positive and linear correlation between dose of blend application and the effect on soil parameters indicators of soil functioning.

3.4. Field trials

After the identification of the more promising blends, the effectiveness of such blends was assessed in field experiments across several European region and with different crops (tomato, cucumber, cover crops, leek, cauliflower, lettuce, grasses, grapes)

The results of field trials suggest that blends of BBFs at appropriate dose can act as a substitute, at least partially, of mineral fertilizers. In general, similar level of productivity were recorded for BBFs blends and reference fertilizers. Moreover, the preliminary results of the trials suggest a positive effect of BBF on several properties of soil linked with nutrient availability, microbial status and climate change (C sequestration). In grapes also a positive effect on the quality of the yield has been detected. These results need to be confirmed in further field experiments but suggest that BBF application may have a positive impact, besides crop productivity, on several ecosystems functions.

3.5. Conclusions

Results of field trial showed the technical feasibility to substitute mineral fertilizers with novel BBF from fruit and vegetable residues. On the other side, the analysis performed by RUSTICA on economical, legal and environmental (non-technical) aspects of BBF production showed that, at present, the most relevant barriers that hampers the development of biobased fertilizers are the legal framework that still does not recognize the most novel fertilizers products (such as insect and microbial biomass) and to the relatively higher production cost of BBFs. However, it is likely that evolution in the legislation will bring in a near future to full acceptance of novel BBF, provided they guarantee consistency in properties and the lack of adverse effects for the environment and the health. Concurrently, economy of scale and the increased diffusion of the conversion technologies will lead to a decrease in fertilizer production costs. These considerations, along with the increase in national and international policies promoting circular food economies and sustainable agriculture, the enhanced environmental awareness of citizens, the raising demand of more healthy food, suggest that the biobased fertilizer sector is likely to have a significant development in the next years.

4. AGRO-INDUSTRIAL WASTE AND CIRCULAR ECONOMY: R&I PROJECTS BASED ON HYDROTHERMAL, BIOCHEMICAL AND EXTRACTION PROCESSES BY THE GREEN PROCESSES ENGINEERING GROUP AT THE UNIVERSITY OF TRENTO.

4.1. Introduction

This section aims to provide an overview of the research activities and related projects carried out by the Green Processes Engineering Group (GPEG) of the University of Trento (UniTN) focused on the valorization of agro-industrial organic waste. The research group is coordinated by Prof. Luca Fiori and has been operative at UniTN for twenty years, with several collaborators who have alternated over the years.

The R&I activity addresses the following residual biomasses from the agro-industrial, zootechnical, and aquaculture sectors:

- Grape marc, residual from both the winemaking and distillation processes
- Olive pomace and olive mill wastewater, residual from the olive oil production process
- Apple pomace, residual from the production of apple juice and fruit not suitable for marketing
- Tomato processing waste, from the tomato sauce production
- Fish (namely, trout) processing waste, i.e. fish viscera, heads, bones, skin
- Manure.

Other biomasses investigated are from the urban organic waste sector: the organic fraction of municipal solid waste (OFMSW), sewage sludge from the wastewater treatment, residual bioplastics.

Such residual biomasses, at the GPEG, are subjected to different conversion processes: physic-chemical, e.g. extraction, biochemical such as anaerobic digestion and composting, and thermochemical, with a peculiar emphasis on hydrothermal processes, but we also investigate dry processes such as pyrolysis and physical activation.

From these process operations, often conducted in cascade with a typical biorefinery approach, several products are obtained. They possess different nature, and can be used in multiple sectors, such as (a list of sectors – products follow):

- Food and/or nutraceuticals: fish oils (possibly enriched in omega-3), seed oils, and bioactive extracts with antioxidant capacity (e.g. lycopene, resveratrol, polyphenolic compounds, E vitamin)
- Agriculture: soil improvers and fertilizers such as biochar, compost, and the innovative hydrochar co-compost, later referred to
- Green chemistry: platform chemicals, i.e. chemical building blocks for organic synthesis
- Energy production: biogas, biomethane, char
- Advanced carbon-based materials: adsorbent materials featuring similar properties to activated carbon; materials for technological applications (carbon electrodes).

The GPEG keyword is “circular bioeconomy”, declined with the expertise and the tools typical of the chemical and process engineering: apart from the lab activity, we perform process design, modeling, simulation, intensification and optimization, so to maximize the recovery of mass (in particular, carbon) and energy and to minimize waste streams.

4.2. The main processes

Among all the technologies available for biomass thermochemical conversion (e.g. gasification, dry pyrolysis, combustion), we particularly deal with hydrothermal processes, such as thermal hydrolysis, hydrothermal liquefaction, supercritical water gasification, with a great focus on hydrothermal carbonization.

We have also high-level expertise in the food engineering sector. In this field, our research principally concerns the extraction of compounds of interest from food residues by using supercritical CO_2 or alternatively, classical extraction methods.

Hydrothermal Carbonization (HTC) is a thermochemical process for organic waste conversion into valuable materials. During HTC, the organic matter in an aqueous suspension is transformed in a short time (1-3 h) at moderate temperatures (180-250 °C) and pressures (10-50 bar) in a solid carbonaceous material, named hydrochar. Hydrochar has different applications: sustainable solid biofuel, soil improver, precursor for activated carbon, carbonaceous material for fuel cell electrodes, as schematically sketched in Fig. 1.

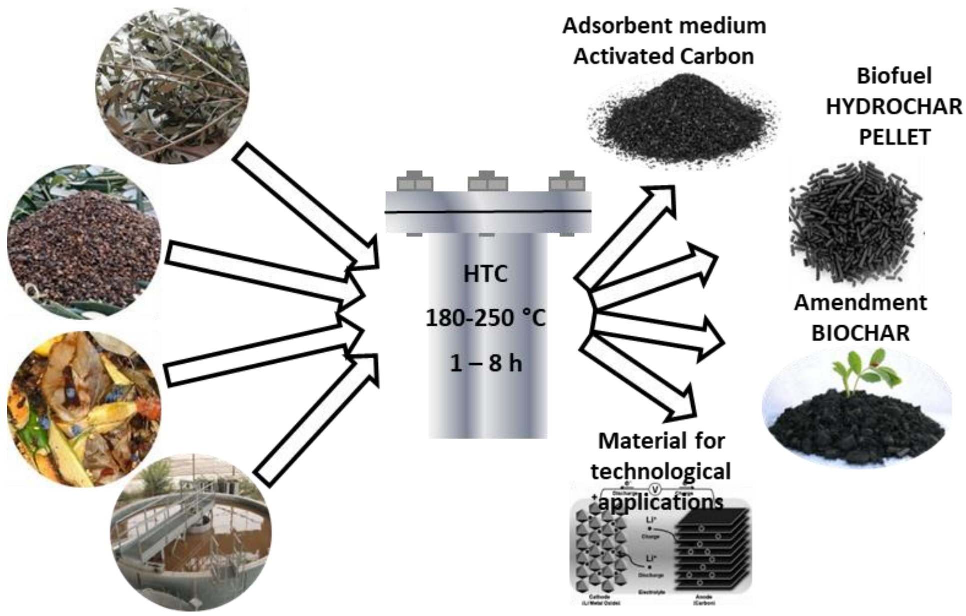

Fig. 1 - An indicative scheme of different biomass types suitable for HTC and possible HTC solid products

The HTC process is suitable for high moisture residues (>50 wt. %), as is the typical case for organic residues and waste biomasses. HTC can be a CO_2-neutral process, is adaptable to a small-scale industry context, could be implemented easily in existing plants (e.g. composting and anaerobic digestion plants), allows the use of raw biomasses without any pre-drying step, is finally a relatively simple and fast technology.

Supercritical CO_2 (SC-CO_2) extraction offers interesting advantages: CO_2, differently from common solvents, is not toxic, not flammable and environmentally not harmful. The drawbacks of the technology lay in the high pressure necessary for the extraction (hundreds of bars). This makes the cost for the supercritical extraction plant greater than the cost for standard extraction equipment, while the operating costs result, generally, similar. The supercritical extraction process is (rarely) industrially adopted for the better quality of the extracted compounds and, all in all, when the extracted substances have a significant added value. In Italy there is a single large industrial supercritical CO_2 extraction plant for the decaffeination of coffee plus many others at a smaller scale. In some other countries the technology finds a larger application.

4.3. The projects

We list below the projects by the GPEG that concern the valorization of agro-industrial waste, reporting for each of them a brief description and referring, where available, to the relevant scientific literature where the interested reader can find more information and research outcomes. The list is in descending chronological order.

Development of a platform for the production of bioactive ingredients from tomato industry waste

The project, funded by the Italian Ministry of University and Research – PRIN PNRR call, sees the involvement of the University of Milan as scientific coordinator and of UniTN-GPEG as research partner. The project, started in December 2023, aims at developing a platform to obtain bioactive fractions (lycopene, polyphenols, polysaccharides and proteins) from tomato pomace residual from tomato sauce production. The technologies under investigation to develop the platform are SC-CO_2 extraction and subcritical water extraction.

Valorization of apple production waste

This is actually comprised in the project mentioned in Section 1: “SMS-GREEN” PROJECT: FROM APPLE POMACE TO SOIL AMENDMENTS”. Consorzio Melinda Snc has entrusted UniTN-GPEG with the development of a circular bioeconomy path applied to apple waste to produce soil amendments through HTC and composting. By putting in series HTC and composting, we obtained what we named “hydrochar co-compost”, similarly to what we did in the previous *C2Land* project where the feedstock to valorize was instead OFMSW digestate (Scrinzi et al., 2022; Bona et al., 2022). In the path of the apple waste project, the liquid phase resulting from HTC is utilized to produce biogas through anaerobic digestion.

Valorization of livestock manure

Circular bioeconomy applied to a) pig-manure to produce biogas and improve its management through HTC and anaerobic digestion (Ferrentino et al., 2023); b) cow-manure for phosphorus recovery and adsorbents production via HTC (Goldfarb et al., 2022).

Valorization of trout processing by products for omega-3 rich oil and fish meal production

With the title above, we summarize four different projects that took place in different years (the last in 2022, the first in 2009) in collaboration with ASTRO, the Association of Trentino Trout Farmers.

We started with a feasibility study for the recovery of omega-3 from trout processing waste (Fiori et al., 2012), then we developed a process for the enrichment in omega-3 of raw fish oil extracted from trout processing waste (Fiori et al., 2014), further we delivered a project for the industrial-scale production of such an oil enriched in omega-3 (Fiori et al., 2017), finally we offered our technical and scientific support for the production and conditioning of protein meals deriving from Trentino trout processing waste.

Valorization of olive mill residues

We investigated the use of the HTC technology to produce hydrochar pellets from olive pomace and olive mill wastewater. The pellets were then evaluated as energy vector and, alternatively, soil improver, and the liquid phase resulting from HTC as liquid fertilizer (Volpe et al., 2017, Volpe et al., 2018).

VALORVITIS - Valorisation of the wine industry by-products for the production of high-added value compounds

In such a project, funded by Fondazioni in rete per la ricerca agroalimentare - Progetto Ager agroalimentare e ricerca, five academic research units investigated different valorization paths to recover useful compounds and fractions from grape marc: sugars, hemicellulose, cellulose, lignin, phenolic compounds, fibers, and oil from, respectively, grape stalks, skins, and seeds. GPEG was in charge of the SC-CO_2 extraction of grape seed oil (Fiori et al., 2014; Duba et al., 2015; Lavelli et al., 2016). GPEG was invited to join the consortium considering its extensive experience in the field (Fiori et al.,2007). VALORVITIS project was followed by other investigations intended to valorize by-products of the wine and distilling industry as solid biofuels (Basso et al., 2016; Basso et al., 2018) and adsorbents (Purnomo et al., 2018), and by a follow-up project through which we disseminated the results of the previous project: VALORVITIS 2.0 - Research and innovation meet the market.

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