

eip-agri  
AGRICULTURE & INNOVATION

## EIP-AGRI Focus Group – Circular horticulture Mini-paper – *Circularity and/or Valorisation of Biomass: Crop Residues, By-products and Extraction of Molecules*

*Stefanie Grade (Coord.), Ellen Berling, Belén Blanco, Rafaela Caceres, Javier Garcia Checa, Sara Di Lonardo, Patrick Lemmens, Juan José Magán, Bart Vandecasteele, Robert Veberic*

### Introduction

Horticultural biomass has a high potential for circularity. This paper focuses on biomass and biomass by-product streams as well as potential valorisation strategies in a horticultural context. Valorisation can be achieved by both high-tech and low-tech solutions. Depending on the location of production, these solutions can be realised by growers and farmers on-site, but the need for high financial investments can lead to off-site solutions that force off-site partnerships and thorough planning of logistics. In case that further use as material (e.g. as building material, chemical feedstock, fertilizer, soil improver) or as food or feed can be ruled out, it can be repurposed as alternative fuel source. This mini-paper highlights the state-of-art use of horticultural biomass streams, explores local solutions and identifies potential markets that can benefit from horticultural by-products.

### Identification of potential uses for horticultural biomass streams

One example for the vast amount of biomass produced alongside a crop can be given for tomato. In 2016, 265,248 ha of tomato were harvested throughout Europe (EU-28; FAO, 2016). The production of tomatoes (in metric tonnes) by each European Country can be seen in Fig. 1. Manzano-Agugliaro (2007) estimates that for tomato crops 49 metric tons of additional biomass are produced per ha and year. Combining these numbers, a biomass stream of almost 13 million metric tons can be estimated for the production of tomato only.



Fig. 1: Production quantity of tomatoes by country  
(Source: <http://www.fao.org/faostat/en/#data/QC/visualize>)

Three different potential uses for biomass streams were identified and categorised in descending order of valorisation potential: 1) nutritional/pharmaceutical use, 2) material use and 3) energy use. In all cases, the seasonal availability and quality of the biomass streams, heterogeneity of the material as well as possible accumulation of contaminants including chemical plant protection residues must be accounted before tapping into their potential. Examples for good practice in each category will be presented in the section “Valorisation of Biomass”.

## Circularity of biomass: Transport, logistics and regional limits

Before biomass can be used by growers and farmers on-site, a number of questions have to be answered:

- Who produces the biomass?
- How and when will the biomass be used – directly or after processing? Who will take care of the processing?
- Will there be a steady supply of biomass or seasonal fluctuations in quantity and quality?
- Will the farmer/grower have to provide storage or processing space? Is there any need for additional equipment (e.g. new combustors, composting equipment) and what is the investment needed?
- Are there specifications or thresholds to be taken into consideration (components, nutrients, residues)?
- How does EU legislation affect the process?

For valorisation, the streams have first to be quantified and checked for their potential. The local use of biomass should be preferred over long distance transport. Defining a sustainable action radius for biomass transport depends on the type of biomass to be transported and the value of the final product. While straw-like materials have a low bulk density of 24-111 kg/m<sup>3</sup> (Lam et al., 2008), fresh crop residues (e.g. leek: 120-330 kg/m<sup>3</sup>) or spent growing media (200-375 kg/m<sup>3</sup>) are much heavier (Viaene et al., 2017). Transport costs are region-specific and highly depend on the local infrastructure and traffic, but they are overall higher for materials with higher moisture contents (green waste: 30-80 %) than for dry biomass waste.

For corn stover in Canada, collection and transport within a radius of 100 to 125 km is profitable from an economical point of view (Marchand, 2015). However, for biomass with higher moisture content this radius will be less than 30 km. In Almería, the pickup and transport cost for biomass waste to a recycling plant is 70 € per 25 m<sup>3</sup> for a maximum transport distance of 12 km. This price has to be increased by 1 € per additional km. The volumetric waste load per ha can be reduced by partially drying the biomass in greenhouses before removing the plants at the end of the crop cycle. This is possible in Mediterranean greenhouses at the end of spring or beginning of summer if a new crop is not going to be planted immediately.

A reduction of the plant biomass humidity content from 80 to 17% in a period of 12 days after cutting the plants has been reported (Fernández-Fernández et al., 2013). For tomato, 75 m<sup>3</sup> of fresh biomass can be decreased to 60-65 m<sup>3</sup> and 50 m<sup>3</sup> for cucurbits. The reduction is not significant in case of woody or lignin-rich crop residues like pepper or eggplant.

A local treatment in container plants (Fig. 2), i.e. on-site biomass treatment, can be another solution. Such systems are easily transported between production sites. Since the systems can be installed in-situ, the need of transferring biomass to off-site treatment plants or sewer systems (in case of waste water) is eliminated, so that transport costs and/or fossil fuel consumption are avoided.



Fig. 2: Container plant for anaerobic digestion

By in-situ biomass treatment, the amount of by-products accumulated on-site will be eliminated and transformed into valuable products, thereby decreasing the costs of site preparation and the risk of water and air contamination, health risks and nuisance by insects.

Fundacion Cartif has carried out several projects using this kind of pilot plants:

- LIFE REVAWASTE (<http://www.revawaste.eu/>): The general aim of the project is the sustainable management of a broad spectrum of wastes (non-recyclable fraction proceeding from waste treatment plants and industrial wastes, together with biomass, livestock and agro-food wastes) in a portable and integrated plant. This objective is reached by means of the technological development and practical application of the "mixed plant" concept which includes anaerobic digestion and pyrolysis technologies.
- LIFE LEACHLESS (<https://lifeleachless.eu/>): The project proposes a portable treatment model that will be carried out "in-situ" using a cost-effective novel technology that combines solar evaporation/condensation plus forward osmosis. The prototype will be powered by renewable energies (solar energy, biomass and residual heat), which will minimise the carbon footprint of the process.
- LIFE ALGAECAN (<https://www.lifealgaecan.eu/>): The project proposes a sustainable treatment model of highly loaded and salty effluents that combines in a portable pilot plant for cost-effective heterotrophic microalgae cultivation with spray drying of the collected microalgae to obtain a product of commercial interest as raw material for the production of biofertilisers, animal feed, bioplastic, etc.

If local use of biomass is not technically or economically possible (e.g., low amount), implementing centralised technological centres that can collect various waste streams for valorisation would provide a cost- and energy-efficient solution. Moreover, prior to transport, it may be advisable to separate the liquid and solid components in order to reduce freights to the next site. The exchange of technical expertise in such centres can provide synergetic effects on all levels. The EIP report on clustering titled "**Clusters Raising Circular Horticulture Bioeconomy**" provides an overview on this matter. The investment into new technologies could be split among different producers and even markets. Each participant could define the preferred specifications for the input material, providing solutions for pre-treatment, processing and subsequent use of biomass. Extraction of high-value components (e.g. treatment with organic solvents, strong acids or lyes) may render the material unusable for further valorisation or recycling steps. If possible, "greener" extraction methods using supercritical CO<sub>2</sub> or hot water as solvent should be employed.

### Nutritional and Pharmaceutical Use

On a regional level, use of biomass for food, feed, material and energy have been identified as feasible. The production of pharmaceutical or nutritional supplements, however, will often require expensive equipment and processing so that it will most likely not be realised by growers/farmers themselves. Processing unattractive crops to pastes, jams or juices is an inexpensive method that has been used for decades. Hence, the creation of a cross-sectoral network for bio-economy is desirable to connect different kinds of industries with different application fields and different needs to the horticultural value chain. In areas with high concentration of greenhouses (e.g. Almería, Spain and Westland, Netherlands) such networks have already been created or are currently being formed and may serve as an example for future collaborations.

### **Material use**

When using biomass, including crop residues or spent growing media, some sort of pre-treatment will often be necessary. Non-biodegradable materials such as strings or clips must be removed and the material must be tailored (e.g. defibration, chopping, screening, mixing, and aging) to ensure homogeneity and stability and to optimise their characteristics.

Materials with low nutrient contents may be considered for direct use as organic soil improver and alternative constituent for growing media (e.g. plant and wood fibres). Materials with high N, P and/or K contents can often directly be used as fertiliser, sometimes undergoing a temperature treatment for sanitation. Composting is one way to first process materials not directly applicable for the applications mentioned above. The combination and balance of different biomass streams with different nutrient contents is a challenge and opportunity on regional level.

### **Energy use**

Depending on the location of the production, combustion or gasification of horticultural residues may be attractive to heat greenhouses or nearby buildings. Seasonality may play an important role in the realisation of such a project because the occurrence of biomass streams and the heating demand can coincide, or not. If not, how can biomass be optimally stored for this purpose? Is the production of electricity via a biogas plant possible and profitable? In case of energy production and use, synergetic effects of producing regions or eventual subsidies from EU or regional governments may play an important part in investment decisions.

## **Valorisation of biomass**

### **Nutritional and pharmaceutical use**

In horticulture, fruits and vegetables (F&V) production can lead to a substantial amount of non-marketable produce that is often sold cheap to the processing industry or simply disposed of through various channels (e.g. brought back as fertiliser to the fields).

The residues of F&V crops are attractive sources for food ingredients, dietary supplements, or novel bio-components. Indeed, bioactive compounds from horticultural by-products have potential for both food and feed formulations since they comprise an excellent pool of molecules to produce nutraceuticals, functional foods, and food additives (Joana Gil-Chávez et al., 2013). F&V represent the simplest form of functional foods because they are rich in several bioactive compounds. Extraction of such molecules can take place in so-called biorefineries as presented by Kips et al. (2016). Phytochemical compounds found in vegetables (mainly phenolic compounds and carotenoids) as well as dietary fibres are reported to have health protective effects that are partially attributed to their antioxidant properties (Pino-Garcia et al., 2016; Perez-Jiménez et al., 2013; Saura-Calixto et al., 2010). Fruits containing polyphenols and carotenoids have been shown to have antioxidant activity and diminish the risk of developing certain types of cancer (Day et al., 2009). Considerable efforts have been made to obtain naturally functional ingredients with health beneficial properties (such as reducing LDL-cholesterol) that can be incorporated into food and feed products (e.g. soluble fibres or phytosterols).

The extraction of molecules for pharmaceutical purposes or dietary supplements may be a new source of income for growers and farmers. However, there are limitations related to the seasonal and local production, variable composition depending on the raw material, the lack of information regarding

application (e.g. in animal nutrition or the presence of anti-nutritional factors). Extraction methods and equipment are fairly expensive and require knowledge and experience. Depending on whether the extraction is performed on- or off-site, the biomass stream may or may not be available for further material use (e.g. composting) by the growers/farmers. Transport of biomass to the site of extraction may be costly, hence, a separation of liquid and solid fractions may be required. F&V residues can be used for animal nutrition, either directly or ensilaged for later use.

The reuse of biomass in any step of the food chain should be checked in terms of safety of the products to be sure that possible pollutants have been removed or would not affect the health of the population.

The following examples were identified as potential approaches to valorise biomass streams for nutritional or pharmaceutical purposes:

- *Production of insects on waste biomass as fat and protein source*

Arthropods can develop on different sources of organic matter, e.g. fruit and plant waste. In that way, plant biomass can be converted into animal flour with a higher content of proteins and fats, which can subsequently be used as an ingredient for or additive to feed for livestock, aquaculture or pets. Furthermore, high value products such as chitin, antibiotics or peptides with bio-stimulant activity can be extracted. These components can give an added value to the feed in comparison to presently-used protein sources (e.g. soya), thus reducing the demand for antibiotics in animal production. At the moment, this technology has not been commercially applied in Europe due to law restrictions but, in 2017, the EU approved the use of arthropods obtained from plant biomass for food applications and there is presently a rekindled interest in it.

For example, a plant for the valorisation of the residues obtained in the agri-food industry by using this technology is being planned in Murcia (Spain) and one already operational in Flanders (<http://www.millibeter.be/>).

- *Production of insects from biomass waste: Bioflytech (<http://bioflytech.com>)*

A circular approach company (based in Alicante) for the management and recovery of organic residues and by-products through larval bio-digestion.

Bioconversion or biotransformation of plant material is achieved by biological agents and processes, transforming them into high value products. An example is shown in Fig. 3. The product derived from larval digestion includes a high-quality homogeneous and physically as well as chemically stable organic fertiliser with excellent agronomic properties for domestic use or to be marketed in agriculture. The process is compatible to organic production standards.

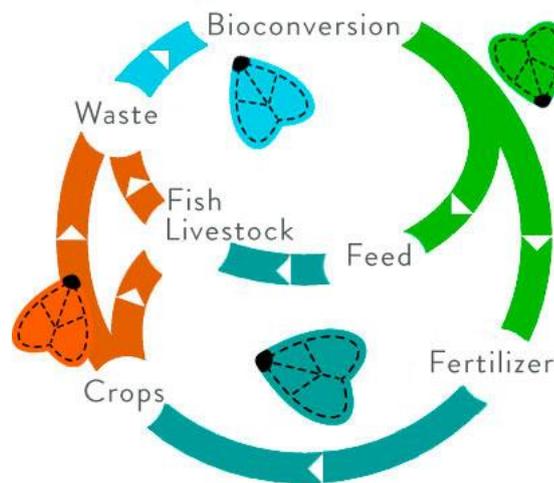


Fig. 3: Concept of bioconversion and circular economy (Source: <http://bioflytech.com/wp-content/uploads/2017/03/bioconversion-eng.jpg> , 19.03.2018)

- *Biopesticide from fermented tomato plant waste* (Friedman et al., 2004; Kalogeropoulos et al., 2012)  
It is known that strains belonging to the genus *Bacillus* can control the development of phytopathogenic fungi due to the production of lipopeptides, proteases and kinases that degrade the fungal structure. Four endophytic *Bacillus* strains, isolated from roots, stems and leaves of tomato plants show growth inhibitory activity against *Botrytis cinerea* because of the production of heterogeneous mixture of antibiotics belonging to fengycin, surfactin, iturin and bacillomycin. This antifungal activity could be used for biopesticide production.
- *Pectin as edible food coating* (Ciolacu, 2014; Giovanetti et al., 2012; Valdés et al., 2015)  
Pectic substances can be obtained from fruit and plant waste such as apple pomace or citrus mesocarp. Pectins are currently used for edible coatings of fresh and minimally processed fruits and vegetables. The functionality has been reported as "excellent barrier to oxygen, aroma preservation, barrier to oil and good mechanical properties, but they are not effective against moisture transfer through films due to their hydrophilic nature".
- *Vegetable waste for the production of natural aroma for the food sector* (Edris et al., 2002; Soares et al., 2000)  
The utilisation of non-edible plant parts by fermentation for the production of volatile compounds of industrial interest has been proposed. Melon and garlic residues (aerial biomass) have been tested to obtain effective aroma.
- *Production of single cell protein (SCP) from food and agricultural waste by using *Saccharomyces cerevisiae** (Gervasi et al., 2018)  
In this study, the production of single-cell protein (SCP) by using food waste as a substrate was investigated. An increase of SCP from an initial content of 15.3 % to 39.8 % was achieved. The use of non-marketable fruits and vegetables for this purpose is conceivable.
- *Onion waste stream for the production of dietary fibres and bioactive compounds (quercetin, flavonols)* (Benítez et al., 2011)  
Onion brown skin and top-bottom were shown to be potentially interesting as a source for dietary fibre as well as phenols and flavonoids with high antioxidant activity. The brown skin

also showed a high concentration of quercetin aglycone whereas the outer scales were rich in flavonols. An industrial scale separation has yet to be realised.

- *Valorisation of horticultural by-products into bio-stimulants & biopesticides*  
<http://www.horticell.ugent.be/project/bio2bio-biological-waste-streams-biostimulants-and-biopesticides>

BIO2BIO aims to generate and identify biostimulants and biopesticides from organic waste streams by means of a screening platform encompassing a wide range of in vitro/greenhouse/field bioassays. The objective is to identify the principle ingredient of one biostimulant and one biopesticide and to gain insight into the mode of action of the identified biostimulant or a combination of biostimulants. An important issue with biostimulants is that the active ingredient(s) are not known and their mechanism of action is poorly understood, but BIO2BIO will address this knowledge gap.

Several projects have dealt or are currently working on the valorisation of biomass streams for nutritional and pharmaceutical use. Some examples are:

- *Interreg Triple F project:* [www.foodfromfood.eu](http://www.foodfromfood.eu)
- *Interreg BioBoost project:* <https://www.bioboosteurope.com/>
- *SUSFOOD SUNNIVA project:* <http://sunnivaproject.eu/>
- *CichOpt project:* <http://facesurplus.org/research-projects-2nd-call/cichopt/>

### Material use

The replacement of non-renewable raw materials has been progressing in different sectors for quite some time. While plant fibres were used for the production of textiles and paper for centuries, novel applications for other waste streams from vegetable production are in development. Oftentimes, crops and their residues are used as raw material for composting or vermicomposting. Compost is an attractive organic soil improver and can, to a certain extent, be used as growing medium in plant production, thereby replacing non-renewable resources such as mineral wool and peat, and being a renewable source of nutrients for soilless cultivation too (Vandecasteele et al., 2018). Before composting, however, it should be ensured that all (locally) possible steps in cascading the biomass have been followed through.

The stability and maturation of the compost plays an important role in its possible application in growing media. Only mature green waste compost should be used, otherwise nitrogen immobilisation will occur and result in deficiency syndromes. Low salinity levels of the compost must be ensured for its application in crop production, with standards based on the crop-related degree of sensitivity and the salinity of the irrigation water.

Instead of being composted, different parts of the plants can be used in other industries. Current research topics deal for example with the dual use of green waste for energy purposes as well as for the production of soil improvers or fertilisers. One possible product is biochar which can subsequently be used as a carbon sink and for soil amelioration, but also as a promising additive for growing media, resulting in higher disease resistance against pathogens and inducing shifts in the rhizosphere microbiome (De Tender et al., 2016a; 2016b).

The following examples show how material utilisation of biomass can be realised:

- *Tomato fibres for production of packaging paper material*  
 In the Netherlands, the company "The Greenery" has been using cardboard boxes made from tomato organic waste (leaves and stems) added to recycled paper. The company states on the web site: "Utilizing tomato fibres makes it possible to conserve energy and wood, while giving the tomato stems a second life as cardboard means they can be recycled again and again. Consequently, tomato fibres stay in the production chain longer, and reliance on virgin wood fibres is reduced. To illustrate: one hectare of tomato plants can be used to produce BioBased packaging for some 600,000 kg tomatoes." (Source:

<https://www.thegreenery.com/en/cases/cardboard-box-made-tomato-stems>; 30.01.2018)

- Natural grass for the production of fibres for packaging material*  
Using a mixture of grass fibres and recycled paper, the Finnish company Huhtamaki was able to create a novel packaging material for the transport of eggs. (Source: <http://www.huhtamaki.com/-/greenest-innovative-egg-packaging-made-with-grass-fibers>; 30.01.2018). Packaging materials for fruits or vegetables could likewise be produced.
- Biochar from residues in growing media*  
Biochar utilisation may offer interesting possibilities for the nursery, ornamental or vegetable and fruit sector not only in terms of increasing the effectiveness of irrigation (for its water retention), by replacing peat as well as by enhancing the retention of nutrients and their availability for plant uptake, or enhancing a higher disease resistance against pathogens (De Tender et al., 2016a). Moreover, it can also permit the use of low-quality irrigation water – thereby also reducing the leaching of nutrients such as  $K^+$  and  $N-NH_4^+$  (Di Lonardo et al. 2017). Finally, in soil poor in nutrients biochar alone could be effectively used to enhance soil fertility and plant growth and biomass yield. In combination with compost, it may enhance and sustain soil biophysical and chemical characteristics and improve crop productivity over time (Trupiano et al. 2017) and optimise the composting process. If biochar can be produced out of horticultural biomass, it may increase the circularity of greenhouse cultivation.
- Alternative constituents for growing media (green waste compost, plant fibres, mushroom compost)*  
Growing media producers are facing restrictions in peat harvesting and the use of other non-renewable materials (mineral wool or other mineral products). Whether alone or in mixtures, peat is the substrate constituent most commonly used in horticulture to grow seedlings and soilless plants in both vegetable and ornamental sectors (López-López et al., 2016), particularly in Europe (Bonaguaro et al., 2017). The European growing media market size is estimated at about 37 million  $m^3$ , with peat representing 80 % of this amount (Aleandri et al., 2015). Many substrate producers have been successfully using wood fibres and compost in professional growing media, but nitrogen immobilisation is still an issue. There is a need for fast and cheap techniques to screen biomass types for their suitability to replace peat or mineral wool. Many studies have been performed using different feedstock for its use in growing media mixtures after composting (Barrett et al., 2016). Common challenges in using compost in soilless media are due to: immaturity of the compost, poor water holding capacity, and unbalanced salinity and pH (Rogers, 2017; Aleandri et al., 2015; Cáceres et al., 2015). Recently, natural acidification through nitrification using green waste with solid fraction of cattle manure has been a suitable method for obtaining appropriate peat substitutes since pH of compost are normally high (Cáceres et al., 2006; 2016; 2018).  
The use of processed plant fibres (e.g. miscanthus straw, reed straw or flax shives) in growing media allows to reduce the demand for peat and to close resource loops, but the risk for nitrogen immobilisation should be assessed. Successful pre-colonisation of this straw with biological control fungi allows optimising crop cultivation, requiring fewer chemical plant protection product applications, which will benefit the environment and human health (Debode et al., 2018, <https://youtu.be/qfFLVWS3Mo>).  
In mushroom production, the reuse of spent mushroom compost is a good practice, but a complete recirculation is not yet achieved due to degradation during production and recycling. The accumulation of production residues (root system/mycelium, nutrients or chemical plant protection residues) also limits the reusability of growing media. The acceptance of reuse by the farmers and growers for fear of contamination and yield losses may be a major obstacle to consider. Depending on the cultivation method, reclamation/reuse of the growing medium is not possible – the material is either sold with the product (e.g. potted plant) or transplanted into open field production. For other cultivation methods, the recycling potential of spent

growing media should be increased by a feedback loop to the cultivation practices (e.g., aiming at reducing the accumulation of nutrients and chemical crop protection products).

### Energy use

The material use of biomass should always be preferred over energy use. Whenever possible, biomass valorisation should take place before combustion, anaerobic digestion or gasification.

Due to high salt, water and ash content, horticultural residues are no ideal fuels (e.g. tomato greenhouse residue contains about 35 % ash; Fryda and Visser, 2015). The high ash content as well as high salt content negatively affects the calorific value of the material, so combustors have to be adapted to the quality/characteristics of the input material. Otherwise, these unsuitable crop residues may be considered for biogas production. A combination with manure or so-called energy crops to feed the biogas plant will be necessary to achieve acceptable methane concentrations in the biogas. If the biomass and/or energy cannot be used on the location of its production, contracting with local energy consumers can be considered.

### Proposals for research needs from practice

The scope of the presented uses for biomass streams is very diverse. Many examples have, so far, only been realised on a very small scale. The main challenge will be to find horticultural partners or partners from other industries to collaborate with for upscaling these applications. The potential partner industries identified are the food industry for supplements or food ingredients, the pharmaceutical industry (bio-active molecules), the packaging industry, the fertiliser and the growing media industry. However, other industries might also benefit from and contribute to circular horticulture. The following two examples for research need were identified by experts in their particular field:

- *Production of dietary fibres or plant-derived proteins*  
An extrusion process could improve the digestibility of fibres (in terms of solubilisation of insoluble fibre) and also the content and bioavailability of bioactive components from horticultural biomass. Studies on the different process conditions (variables of the process) on extrusion cooking will result in a deeper knowledge to optimise extraction in relation to the type of biomass and potential commercial price.
- *Alternative constituents for growing media*  
The peat or mineral wool replacement in growing media should also be accompanied by optimising the cultivation system based on these new materials, e.g., by adapting the fertiliser application/fertigation needs. It should also take advantage of the nutrients of the alternative materials (e.g., Vandecasteele et al., 2018) and cope with the possible issues regarding their practical management. In this regard, methods to monitor rhizosphere composition for mineral nitrogen availability should be implemented in nurseries and greenhouses (Cáceres and Marfà, 2013). The study of indigenous nitrifying community can be used as a further step towards a more sustainable horticulture, where the delivery and production of organic-derived nutrients can be predicted and controlled (Grunert et al., 2016).  
The use of virgin raw materials (e.g., in growing media) can be reduced by a sequence of measures that allow growers to adopt the new practices for their replacement:
  - Longer use/reuse
  - Partial replacement
  - 100% replacement

It is important to highlight the potential advantages on top of the replacement, i.e., the potential to decrease the need for chemical fertiliser use and chemical plant protection

products, resulting in a lower amount of residues in the growing media increasing their potential for reuse.

## Proposals for Operational Groups

1. Operational group focusing on the extraction of food, feed and high value molecules from biomass. This technology is still expensive. Investigation can be done to test the quality of the biomass and look at the chemical and biological safety. The market potential can be assessed based on the prospective of these secondary products to become an important income source in the future, e.g. extraction of molecules and nutritional components for food printing.
2. Operational group focusing on alternative and renewable growing media. Involve farmers in the process of production of alternative growing media to create trust among growers. For example trying to broaden the spectrum of input material for producing compost as alternative substrate. To link or cluster companies and logistics. To look at the risk of accumulation of contaminants and the potential reduction in new developed growing media blends during cultivation.
3. Operational group focusing on biomass for packaging. Involving the whole value chain for using biomass for packaging (e.g. the production of bioplastics). Distribution is a key player. Also involve the consumer, because what happens with the package material at the consumer?
4. Operational group focusing supporting circularity by linking farmers to other sectors such as urban waste water plants, plastic, textile, metallurgical industries, energy providers, or waste treatments plants (heat).

## Conclusion and recommendations for further development

There is an absolute need for clearly documenting experiences, advantages, disadvantages and trade-offs of innovative techniques to produce valuable end products in a circular horticulture. The evaluation of biomass streams for their valorisation potential is crucial and should be performed for major horticultural crops (vegetables and ornamentals). Valorisation is a top priority and has a high environmental, social and economic impact. Horticultural by-products can be effectively used in extraction for the production of high quality food and feed bio-components. Environmentally friendly and sustainable extraction processes can lead to high value bioactive components. Since consumers as well as large distribution companies/wholesalers are interested in clean labels, ingredients from natural sources and environmentally conscious production, a high acceptance of such products is to be expected.

In this paper, it was clarified that logistics play an important role for an efficient and economically feasible use of biomass. A sufficient quantity of biomass must be available to reduce investment costs for refining equipment and production costs, independent of whether the solution is low- or high-tech. Finally, the goal is a commercially attractive product and optimising transport is a first step.

## References

Aleandri, M.P., Chilosi, G., Muganu, M., Vettrano, A., Marinari, S., Paolocci, M., Luccioli, E., Vannini, A. 2015. On farm production of compost from nursery green residues and its use to reduce peat for the production of olive pot plants. *Scientia Horticulturae* 193: 301-307.

Benítez, V., Mollá, E., Martín-Cabrejas, M. A., Aguilera, Y., López-Andréu, F. J., Cools, K., Terry, L. A., Esteban, R. M. 2011. Characterization of Industrial Onion Wastes (*Allium cepa* L.): Dietary Fibre and Bioactive Compounds. *Plant Foods Hum Nutr* 66:48–57

Bonaguro, J.E., Coletto, L., Zanin, G. 2017. Environmental and agronomic performance of fresh rice hulls used as growing medium component for *Cyclamen persicum* L. pot plants. *Journal of Cleaner Production* 142: 2125-2132.

Cáceres, R., Flotats, X., Marfà, O. 2006. Changes in the chemical and physicochemical properties of the solid fraction of cattle slurry during composting using different aeration strategies. *Waste Management* 2006:1081-1091.

Cáceres, R., Marfà, O. 2013. Diagnosis of the fertility of compost-based growing media: method comparison and monitoring in pot plant production. *Scientia Horticulturae* 164:213-220.

Cáceres, R., Cunill, C., Marfà, O. 2015. Compost que es produeixen a Catalunya: Caracterització i viabilitat del seu ús com a substrat. *Quaderns Agraris del ICEA* 39: 7-34.

Cáceres, R., Coromina, N., Malińska K., Martínez-Farré, F.X., López, M., Soliva, M., Marfà, O. 2016. Nitrification during extended co-composting of extreme mixtures of Green waste and solid fraction of cattle slurry to obtain growing media. *Waste Management* 58:118-125.

Cáceres, R., Malińska, K., Marfà, O. 2018. Nitrification within composting: A review. *Waste Management* 72: 119-137.

Ciolacu, L., Nicolau, A.I., Hoorfar, J. 2014. *Global Safety of Fresh Produce. A Handbook of Best Practice, Innovative Commercial Solutions and Case Studies*; Woodhead Publishing Limited: Sawston, UK.

De Tender, C., Debode, J., Vandecasteele, B., D'Hose, T., Cremelie, P., Haegeman, A., Ruttink, T., Dawyndt, P., Maes, M. 2016a. Biological, physicochemical and plant health responses in lettuce and strawberry in soil or peat amended with biochar. *Applied Soil Ecology* 107, 1-12.

De Tender, C., Haegeman, A., Vandecasteele, B., Clement, L., Cremelie, P., Dawyndt, P., Maes, M. and Debode, J. 2016b. Dynamics in the strawberry rhizosphere microbiome in response to biochar and *Botrytis cinerea* leaf infection. *Front. Microbiol.* 7:2062.

Debode, J., De Tender, C., Cremelie, P., Shein Lee, A., Kyndt, T., Muylle, H., De Swaef, T., Vandecasteele, B. 2018. Trichoderma-inoculated miscanthus straw can replace peat in strawberry cultivation, with beneficial effects on disease control. *Frontiers in Plant Science*, 9, 213.

Del Pino-García, R., González-SanJosé, M. L., Rivero-Pérez, M. D., García-Lomillo, J., Muñiz, P. 2016. Total antioxidant capacity of new natural powdered seasonings after gastrointestinal and colonic digestion. *Food chemistry*, 211, 707-714.

Di Lonardo, S., Baronti, S., Vaccari, F. P., Albanese, L., Battista, P., Miglietta, F., Bacci, L. 2017. Biochar-based nursery substrates: The effect of peat substitution on reduced salinity. *Urban Forestry & Urban Greening* 23: 27-34.

Edris, A. E., Fadel, H. M. 2002. Investigation of the volatile aroma components of garlic leaves essential oil. Possibility of utilization to enrich garlic bulb oil. *Eur Food Res Technol* 214:105-107.

FAO, 2016. Link: <http://www.fao.org/faostat/en/#data/QC>, retrieved 15.03.2018.

Fernández-Fernández, M.D., Reinoso-Moreno, J.V., Pérez-Martínez, C., López-Hernández, J.C., Ación-Fernández, F.G., Sánchez-Molina, J.A., Meca-Abad, D.E., Gázquez-Garrido, J.C. 2013. Influencia de las técnicas de recogida sobre las propiedades de residuos vegetales de invernaderos para su aprovechamiento energético. VII Congreso Ibérico de Agroingeniería y Ciencias Hortícolas. Madrid, 26-29th August 2013.

- Friedman, M. 2004. Analysis of biologically active compounds in potatoes (*Solanum tuberosum*), tomatoes (*Lycopersicon esculentum*), and jimson weed (*Datura stramonium*) seeds. *J Chromatogr A* 1054:143–155.
- Fryda, L. and Visser, R. 2015. Biochar for Soil Improvement: Evaluation of Biochar from Gasification and Slow Pyrolysis. *Agriculture* 5, 1076-1115
- Gervasi, T., Pellizzeri, V., Calabrese, G., Di Bella, G., Cicero, N. , Dugo, G. 2018. Production of single cell protein (SCP) from food and agricultural waste by using *Saccharomyces cerevisiae* Natural Product Research Vol. 32, Iss. 6, 2018 [doi.org/10.1080/14786419.2017.1332617](https://doi.org/10.1080/14786419.2017.1332617)
- Giovanetti, M.H., Nogueira, A., de Oliveira, C.L., Wosiacki, G. 2012. Chromatography—The Most Versatile Method of Chemical Analysis; InTech: Rijeka, Croatia.
- Grunert, O., Reheul, D., Van Labeke, M.C., Perneel, M., Hernández-Sanabria, E., Vlaeminck, S.E., Boon, N. 2016. Growing media constituents determine the microbial nitrogen conversions in organic media for horticulture. *Microbial Biotechnology* 9(3):389-399.
- Kalogeropoulos, N., Chiou, A., Pyriochou, V., Peristeraki, A., Karathanos, K. T. 2012. Bioactive phytochemicals in industrial tomatoes and their processing byproducts. *LWT-Food Sci Technol* 49(2):213-216.
- Kips, L., De Paepe, D., Bernaert, N., Van Pamel, E., De Loose, M. Raes, K., Van Droogenbroeck, B. 2016. Using a novel spiral-filter press technology to biorefine horticultural by-products: The case of tomato. Part I: Process optimization and evaluation of the process impact on the antioxidative capacity. *Innovative Food Science & Emerging Technologies* Vol. 38, p. 198-205. [doi.org/10.1016/j.ifset.2016.10.005](https://doi.org/10.1016/j.ifset.2016.10.005)
- Lam, P. S.W., Sokhansanj, S., Bi, X., Lim, J., Naimi, L., Hoque, M., Mani, S., Ray Womac, A., Philip Ye, X., Narayan, S. 2008. Bulk Density of Wet and Dry Wheat Straw and Switchgrass Particles. *Applied engineering in agriculture*. 24. 351-358. 10.13031/2013.24490.
- López- López, N., López-Fabal, A. 2016. Compost based ecological growing media according EU eco-label requirements. *Scientia Horticulturae* 212: 1-10.
- Rogers, M.A. 2017. Organic vegetable crop production in controlled environments using soilless media. *HortTechnology* 27:166-170.
- Manzano-Agugliaro, F. 2007. Gasificación de residuos de invernadero para la obtención de energía eléctrica en el sur de España: ubicación mediante SIG. *Interciencia* 32(2):131–136
- Marchand, L. 2015. Cost Assessment for Cornstalk Supply Chain for Bioprocessing Purposes. University of Guelph, Ridgetown Campus.
- Pérez-Jiménez, J., Díaz-Rubio, M. E., Saura-Calixto, F. 2013. Non-extractable polyphenols, a major dietary antioxidant: Occurrence, metabolic fate and health effects. *Nutrition Research Reviews*, 26, 118–129.
- Saura-Calixto, F., Pérez-Jiménez, J., Touriño, S., Serrano, J., Fuguet, E., Torres, J. L., Goñi, I. 2010. Proanthocyanidin metabolites associated with dietary fibre from in vitro colonic fermentation and proanthocyanidin metabolites in human plasma. *Molecular Nutrition and Food Research*, 54, 939–946.
- Saura-Calixto, F., Serrano, J., Goñi, I. 2007. Intake and bioaccessibility of total polyphenols in a whole diet. *Food Chemistry*, 101, 492–501.

Soares, M., Christen, P., Pandey, A., Raimbault, M., Soccol, C.R. 2000. A novel approach for the production of natural aroma compounds using agro-industrial residue. *Bioprocess Eng* 23:695–699.

Trupiano, D., Coccozza, C., Baronti, S., Amendola, C., Vaccari, F. P., Lustrato, G., Di Lonardo, S., Fantasma, F., Tognetti, R., Scippa, G. S. 2017. The effects of biochar and its combination with compost on lettuce (*Lactuca sativa* L.): growth, soil properties, and soil microbial activity and abundance. *International Journal of Agronomy*, Article ID 3158207

Valdés, A.; Burgos, N.; Jiménez, A.; Garrigós, M.C. 2015. Natural Pectin Polysaccharides as Edible Coatings. *Coatings*, 5, 865-886.

Vandecasteele, B., Debode, J., Willekens, K., Van Delm, T. 2018. Recycling of P and K in circular horticulture through compost application in sustainable growing media for fertigated strawberry cultivation. *European Journal of Agronomy* 96, 131–145.

Viaene, J., Reubens, B., Willekens, K., Van Waes, C., De Neve, S. & Vandecasteele, B., 2017. Potential of chopped heath biomass and spent growth media to replace wood chips as bulking agent for composting high N-containing residues. *Journal of Environmental Management* 197, 338-350, 10.1016/j.jenvman.2017.03.086

Clusters Raising Circular Horticulture Bioeconomy.

Authors: Francisco J. Egea Gonzalez, Joaquim Miguel Costa, Guillaume Morel-Chevillet, Irene Vanninen, Patrick Eninge, Alain Grenet

