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THE HIDDEN VALUE OF AGRI-FOOD RESIDUES, REVEALED AND BOOSTED THROUGH A CIRCULAR APPROACH: AGRO2CIRCULAR

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ABSTRACT: Agro2Circular (A2C) project is achieving the valorization of food wastes obtaining high-value products (new food, cosmetic and nutraceutical formulation) as well as an efficient recycling for each food packaging film family, thus contributing towards an innovative sustainable circular economy concept. The A2C approach will be tested in the Región de Murcia (Spain) and replicated in two other EU countries (Italy and Lithuania), backed up by a circular business model and strong public engagement and co-creation processes, maximizing replicability and scalability. A presentation of the idea, of the current status of the project and first available results will be made.

Keywords: Circular economy, food waste, fruit and vegetables, upcycling

1. INTRODUCTION

Wastes related to food can have a different origin: on one side there is the food wasted in many ways, for example the non-compliant pieces (for size, shape or color) removed during sorting actions, that discarded by retailers or consumers when it’s close to or beyond the best before date, as well as the unused or leftover food that is thrown out from households or restaurants. An estimated 20% of EU food production is currently wasted (Åsa Stenmarck et al., 2016); highly perishable fruits and vegetables (F&V) have the highest rates of loss and waste, usually within the range of 40–50% (Global Panel 2018; FAO 2019).

On the other side, multilayer packaging widely used as industrial packaging for the protection of food and agriculture for crops due to their unique barrier properties can represent another problem; indeed, inefficiencies and complexity of sorting and recycling of multilayer plastic films (MPF) make landfilling (34% of the total MPF waste) and incineration (66%) the only available option, to date.

There is a lack of an economic & environmentally sustainable value chain for the upcycling of F&V residues and multilayer plastic into high added value products. There is a lack of demonstrated and replicable systemic solutions for the territorial deployment of the circular economy.

2. **Agro2circular approach**

2.1 Upcycling of agri-food wastes

For the valorisation of different agri-food wastes (fruits and vegetables), green extraction, purification and stabilisation routes will be used to obtain high value bioactives (phenolic compounds and dietary fibre).

The selected agrifood wastes are citrus, apple, grape, cauliflower, broccoli and artichoke.

The extraction conditions have been optimised taking into account the different operating parameters of each technology at laboratory scale, with the aim of being able to integrate the valorisation routes at industrial scale.

2.1.1 Waste conditioning

Agri-food waste has been washed to remove unwanted particles (dust, soil) as well as possible post-harvest pesticide residues.

Subsequently, they have been subjected to mechanical or physical pre-treatments to reduce the size of the vegetal matrix and homogenise the sample. Particle size reduction is a factor that has long been taken into account as it facilitates mass transfer since the compounds of interest are more exposed to the solvent and therefore increases extraction speed and yields (Panzella et al., 2020). Thus, the plant material is shredded into 20 mm x 20 mm cubes (except for waste that initially has a small granulometry, as was the case with apple waste).

Figure 1. *Particle size difference of apple (left) and broccoli (right) waste.*

2.1.2 Extraction methodologies

In the field of extraction of compounds of interest, it is imperative to reduce the use of reagents and excipients in general and to eliminate the use of hazardous solvents in particular, or at least replace them with safer ones (Janicka et al., 2022).

In addition, assisted extraction techniques are an attractive alternative to conventional solvent extraction methods for extracting bioactive analytes from vegetable materials, as they allow significant improvements in extraction efficiency, provide high yields in short extraction times and reduce solvent requirements (Bachtler & Bart, 2020).

Under these premises, different innovative and environmentally friendly extraction technologies have been employed in the Agro2Circular project, avoiding the use of hazardous organic solvents:

- Subcritical water extraction (SWE)
- Natural deep eutectic solvent extraction (NADES)
- Enzyme-assisted extraction (EAE)
- Ultrasound-assisted extraction (UAE)
- Microwave-assisted extraction (MAE)

2.1.3 Purification and stabilization

Once the extraction process is finished, a liquid phase and a solid phase, rich in different organic compounds of interest, are obtained. These phases have to be treated to eliminate those compounds that are not of interest, thus improving the purity of the compounds to be recovered.

Figure 2: *Fibre (A) unpurified; (B) purified*

Several studies have also shown the importance of keeping optimal storage conditions for extracts, in order to avoid their devaluation. These conditions include temperature, time, water activity and packaging (Petropoulos et al., 2016).

To this end, both extracts have been subjected to purification and stabilisation treatments in order to increase the concentration and purity of the target compounds, as well as to ensure their storage capacity and useful life, respectively.

Table 1. *Purification and stabilisation technologies*

	Purification	**Stabilisation**
Dietary Fibre	Treatments with oxidising agents	Dehydration
Phenolic compounds	Membrane filtration Adsorption resins	Freeze-drying

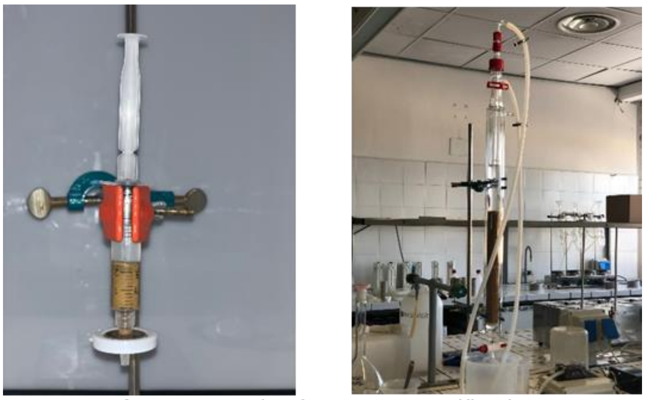

Figure 3. *Resins for extracts purification*

2.1.4 Evaluation of extracts

Once the purified extracts were obtained, the quality of the extract was evaluated according to different parameters.

The extract rich in phenolic compounds was evaluated for total polyphenols as well as specific phenolic compounds (using an HPLC-MS/MS method).

Also, the antioxidant and antimicrobial activity of the extracts has been evaluated.

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In the case of the fibre extract, the dietary fibre content has been evaluated, which have been further characterised by using FTIR-ATR method.

The presence of pesticides in the final extracts (whose presence, although not detected in the raw material, may be due to successive concentrations during the extraction, purification and stabilisation treatment) has also been evaluated.

2.2 Upcycling of post-industrial multilayer films

A value chain for the upcycling of metallised multilayer film waste, coming from industrial food packaging, is being built in the frame of Agro2Circular project.

Several novel technologies have been applied in order to achieve industrial feasibility plus zero waste. These technologies are listed below:

- Optical sorting
- Delamination and aluminium recovery
- Aluminium modification
- Ultracleaning extrusion
- Enzymatic recycling
- Multimaterial blends with enhanced properties

2.2.1 Optical sorting

Iris Technology solutions S.L. is developing a technology focused on sorting (optically and mechanically) the metallised fraction of the plastic shredding, to be integrated in the industrial line for plastic mechanical recycling, in order to obtain two different streams (metallised portion and non metallised portion) which will be further treated in a different way for its proper upcycling.

Figure 4: Plastic shredding to be separated into two different fractions (metallised and non mettalised)

2.2.2 Delamination and aluminium recovery

saperatec GmbH technology is able to delaminate the metallised fraction in order to separate the different layers while removing the aluminium coating/foil. Throuhg this step, which is integrated in the industrial line for plastic mechanical recycling, pure aluminium and monomaterial streams are obtained, materials of high value that can be reused as secondary raw material.

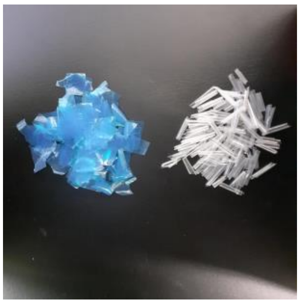
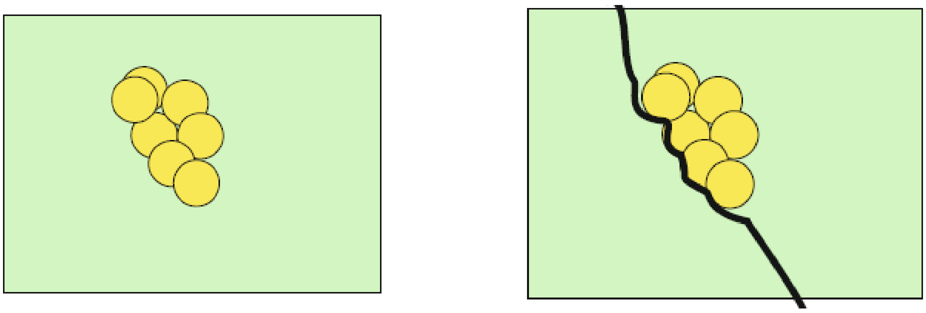


Figure 5: monomaterial fractions *Figure 6: Pure aluminium fraction*

2.2.3 *Aluminium modification*

The University of BOKU has developed a simple, cost effective and scalable method to modify the aluminum fraction in order to increase its hydrophobicity and make it more compatible with plastic matrices. Thanks to this modification, the aluminium particle can be better dispersed in the plastic and can be used as plastic additive to achieve certain type of properties such as effect colour, optical properties or even an improvement of gas barrier properties and mechanical properties.



2.2.4 *Ultracleaning technologies*

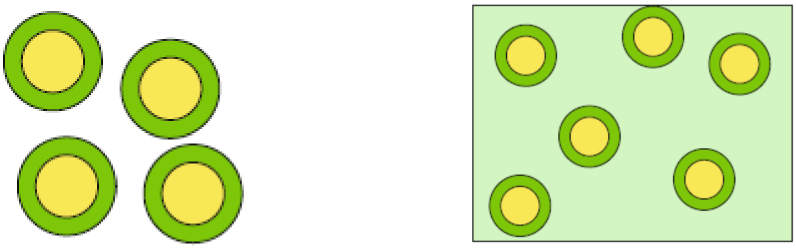


Figure 7: Perfect dispersivity

Green World Compounding is testing several ultracleaning technologies to be incorporated in its mechanical recycling line with the final goal of removing contaminants, non-intentionally added substancies and odour, which will improve the quality of the plastic material and its usability in food packaging. The cleaning effectiveness of the different technologies is evaluated by conducting challenge tests and analysis of NIAS.

2.2.5 Enzymatic recycling

EPOCH Biodesign has engineered novel degrading enzymes that are able to break the remaining bimaterial plastic fraction into its monomers/oligomers, substances that can be used as secondary raw material for the production of building blocks for the biotechnology industry. Both the process for the enzymes production and the process for the plastic degradation are being developed at semi-industrial scale for its final industrial implementation.

Figure 8: Production of enzymes

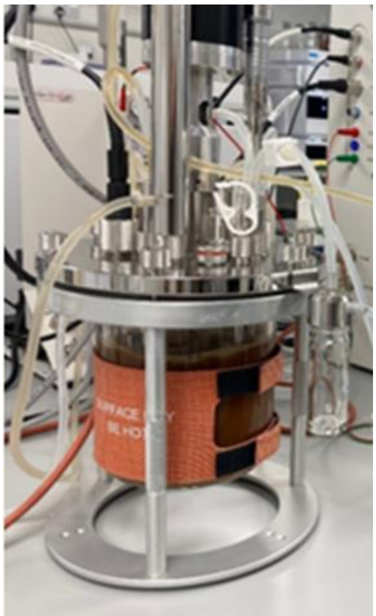
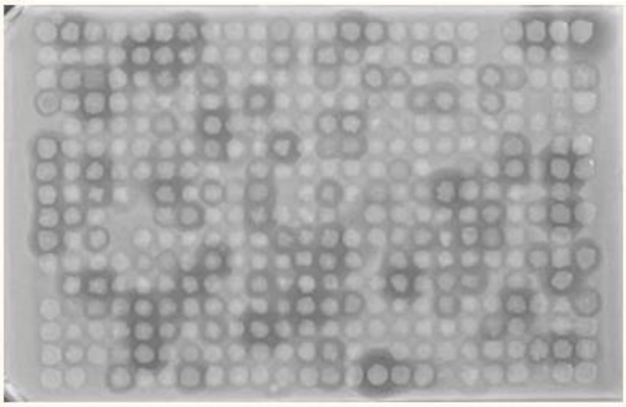


Figure 9: Colony based degradation assay



2.2.4 Enhancement of multimaterial plastic blend properties

CETEC Technological Centre of Murcia is working on improving the final properties of multimaterial plastic blends including the testing of the modified aluminium as an additive for plastics, by using novel polymer compatibilizers and extensional flow mixing.

3. CONCLUSIONS

Agro2Circular (A2C) is EU project boosting the upcycling of agri-food wastes (from F&V) through innovative routes of valorisation, leading to high extraction yields, bioactives with the purity and stability required to be used for the production of new food, cosmetic and nutraceutical formulation. Then, A2C will develop the first recycling value chain for post-industrial multilayer films based on a synergistic approach combining innovative sorting, physical delamination, enzymatic depolymerisation, decontamination & mechanical recycling. The integrated A2C approach will be tested in the Región de Murcia (Spain) as a proof of concept and replicated in two other countries (Italy and Lithuania) for confirming its feasibility and wide application in EU.

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