Turning agricultural waste into ecological and economic assets: ECOBIOCAP experience and NoAW ambition

M. Majone[1] and N. Gontard[2]

[1]Department of Chemistry, University of Rome "La Sapienza", Rome, 00185, Italy
2 INRA, Montpellier, F34060, France, EcoBioCAP and NoAW coordinator
Presenting author email: mauro.majone@uniroma1.it

Driven by a "near zero-waste" requirement, the European society is strongly supporting research and innovation both to reduce waste production and recover waste as a renewable resource, in all economic and social environments, such as agricultural, industrial and urban ones.

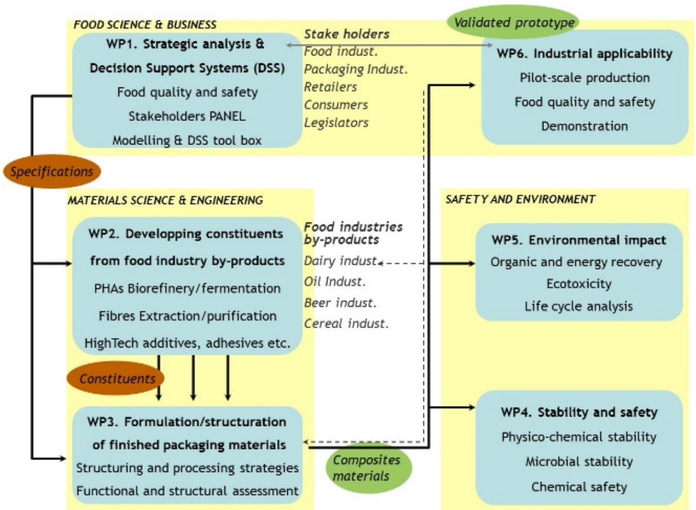
In the frame of the FP7, ECOBIOCAP project was aimed to reduce both food wastage and waste from food retail by developing an "ECOefficient BIOdegradable Composite Advanced Packaging"; as an additional factor, agro-industrial by-products were investigated as the renewable feedstock to produce packaging constituents, so to further contribute to waste reduction and to the development of a bio-based circular economy.

Based on ECOBIOCAP approach, results and lesson-learnt experience, the NoAW ("No Agricultural Waste") project has been developed and is presently being started in the frame of Horizon2020 (SC5, Topic: Waste 7, RIA). NoAW is a larger and wider-purpose project, whose basic idea is to convert several agro-waste, that are mostly unavoidable and continuously generated, into sustainable wide range of bio-energy, bio-fertilizers, bio-packaging and bio-chemicals by the use of cascading processes. To achieve this goal, the NoAW concept relies on developing holistic life cycle thinking and assessment able to support environmentally responsible R&D innovations on agro-waste conversion at different TRLs, in the light of regional and seasonal specificities, not forgetting risks emerging from circular management of agro-wastes (e.g. contaminants accumulation). Here, both ECOBIOCAP experience and NoAW ambition are briefly summarised.

The ECOBIOCAP project

EcoBioCAP (**http://www.ecobiocap.eu/index.php**) was a 4-year FP7 collaborative research project **(**Theme KBBE.2010.2.3-01, Development of biodegradable food packaging), made by 16 partners from 8 European countries and 3 millions € EC grant. EcoBioCAP aimed at providing the EU food industry with customizable, ecoefficient, biodegradable packaging solutions. In order to develop this next-generation packaging, process advancements to produce several constituents (biopolyesters, fibres, proteins, polyphenolic compounds, bioadhesives and bio-additives) from food industry by-products (oil, dairy, cereal and beer) were investigated; then, advanced composite structures were explored by applying innovative processing strategies to enable customisation of the packaging's properties to fit the functional, cost, safety and environmental impact requirements of the targeted fresh perishable foods (fruit and vegetable, cheese and ready to eat meal). Demonstration activities with SMEs and industrial partners enabled the EcoBioCAP technology and products to be checked, towards obtaining full exploitation. As reported in figure 1, the EcoBioCAP was organised by 6 WPs (plus WP7 and WP8 for dissemination and management, respectively) which were strongly interconnected.

Figure 1 EcoBioCAP structure.



In the **WP1 - integrated analysis of packaging specifications, dimensioning and decision support system**, packaging requirements for maintaining quality and safety of respiring and inert fresh foods were assessed and stakeholders needs were mapped and analysed. A systematic approach was applied to develop the packaging specifications of targeted products, based on agreeing on packaging development briefs, collecting the available knowledge, carrying out experimental work and consumer surveys. Then a decision support system (DSS) was developped which a) computes the list of the relevant packaging by taking into account the virtual Modified Atmosphere Packaging (MAP) model and data stored in food and packaging databases, and b) aggregates preferences expressed by the stakeholders into consensual preferences using an argumentation approach.

In the **WP2 - development of packaging constituents by upgrading food industry by-products,** the production, characterization and optimization of three mains constituents, to be used for formulating packaging in WP3, were performed:

a) microbial polyesters (polyhydroxyalkanoates, PHAs) from liquid effluents: PHAs with targeted functional properties have been successfully synthesized from olive mill wastewaters (OMW) and cheese whey (CW), by using a novel biological process which is based on microbial mixed consortia (MMC), rather than presently used pure cultures. Interestingly, the copolymer PHBV (i.e. the copolymer between hydroxybutyric and hydroxyvaleric acids, HB and HV respectively) was obtained in a wider range of monomeric compositions than commercially available, that enlarges the spectrum of polymer properties and improves its processability.
b) fiber-based fractions from solid by-products were obtained from wheat straw, brewing grains and olive pomace. Impact milling process was selected as the best compromise between particle size and energy consumption.
c) tailored and high performance additives and adhesives: Cellulose Nano Cristals were extracted from Wheat Straw (WS), Brewing Grains (BG) and Olive Pomace (OP), the latter showing lower aspect ratio and crystallinity index. However, the extraction yields attained in all the cases were very low as compared to, for example, bacterial cellulose, that suggested a non-economical viable process. Pure keratin was extracted from chicken feathers. Anti-oxidant nanoclays were successfully developed from polyphenolic extracts of olive waste water and pomace as well as bio-adhesives based on zein and pullulan.

In the **WP3 - formulation and structuration of finalized materials**, the best respiring bio-composite materials were obtained from PHBV and wheat straw fibres (up to 30%) by thermo-moulding process, with increased gas (O_2 and CO_2) and water vapour permeability with wheat straw content. Barrier properties of PHBV monolayers obtained by casting and melt-compounding were improved by adding cellulose nano-crystal and antioxidant nanoclays derived from polyphenols. To improve the mechanical properties of PHBV and composites, plasticizers and others bio-polymers were introduced in the formulation. Multilayers lid films and trays were developed by combining PHBV and composites with others bio-polymers and by using various processing technologies such as electrospinning technology. The extrusion blowing of bi-layered films seemed to be a very prospective option in terms of avoiding thermal load and resulting properties. Functional properties of developed structures were analysed in relation with their structure at different scales, morphology and thermal stability.

In the **WP4 - Assessment of packaging physical-chemical stability and chemical safety**, an excellent stability of PHBV based materials during storage, in contact with micro-organisms and with all types of foods simulant was demonstrated, except with ethanol 95% for which a significant swelling and an excess of overall migration (OM) were obtained. Introducing wheat straw fibres into the formulation increased OM with polar food simulant only, so narrowing the use to low or intermediate water activity products and/or fat products. By artificially adding a few selected contaminants to different feedstock (e.g hexachlorocycloexane to cheese whey), very good abatement during production and processing was shown which introduces an additional barrier againts toxicological risks.

In the **WP5 - Assessing the environmental impact of the new biodegradable materials**, recommendations for optimizing formulations and manufacturing processes were elaborated based on LCA perspectives. Eco-toxicity test feasibility was demonstrated.

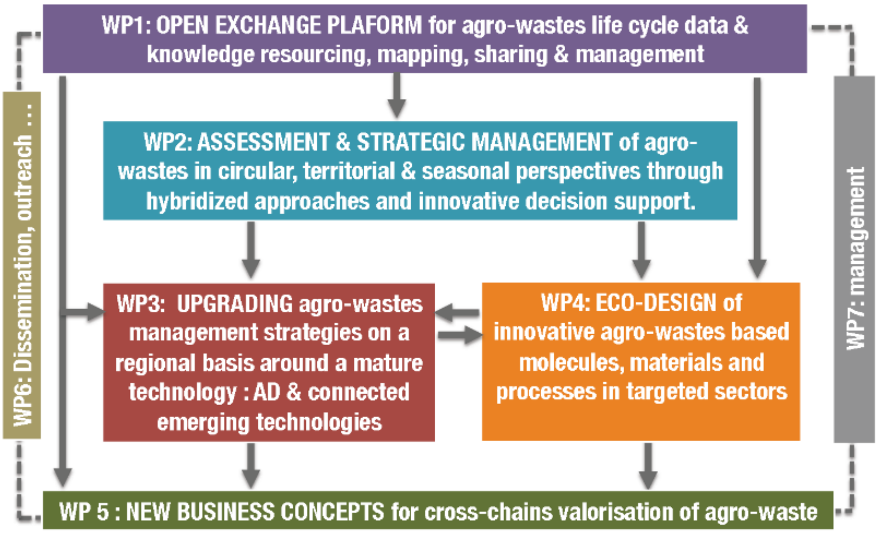
In the **WP6 - Industrial Applicability**, the production of PHBV from cheese whey, wheat straw fibres fractions, cellulose, lignin rich fractions and zein-based adhesives were upscaled to small pilot plant. Moreover, a packaging prototype (for strawberries) was realized and checked by a consumer survey (through a questionnaire and tasting sessions) and by a shelf life study. The proposed EcoBioCAP packaging did not have any significant negative impact on sensorial attributes of strawberries in comparison to benchmark packaging. However, for further improvement it would be benefit a more transparent packaging, which was consumers' most important expectation for fresh strawberry product. As for shelf life study, good performance was shown, but the required permeability level of the lidding film which was not reached and the lidding film was found a bit breakable.

Last but not least, in the **WP7 – Outreach, EcoBioCAP** activities and results were intensively disseminated along the whole project duration, by using the EcoBioCAP website, brochures, newsletters and various public exhibitions. A very active involvement of the stakeholders' advisory board has to be mentioned. Overall, the EcoBioCAP showed the feasibility of developping advanced biodegradable packaging to better preserve food while using food-industry by-products as a renewable feedstok for packaging constituents. For a few remaining single targets, EcoBioCAP offered the additional knowledge needed for possible further improvements.

The NoAW project

NoAW (No Agricultural Waste) is about developing a circular economy approach applicable to a gricultural wastes on a territorial and seasonal basis. NoAW aims to pave the way for a sustainable agro-waste bio-refinery concept by shifting from an a-posteriori environmental assessment to an early eco-design approach. NoAW targets to unlock the potential of agro-waste to be converted into a portfolio of eco-efficient products: bio-energy, bio-fertilizers, bio-packaging and bio-molecules, in symbiosis with urban waste conversion. NoAW is a European-Chinese Research Innovation Action supported by a 7 millions € EC grant, gathering 16 academic and 16 private partners and focusing on 5 main geographical case-studies: Languedoc-Roussillon (France), Veneto (Italy), Bavaria (Germany), Netherland, Denmark, and also in Serbia, Portugal, Switzerland and China. As reported in figure 2, NoAW is organized in 5 scientific WPs, one dissemination and one management WP.

Figure 2 NoAW structure.



Based on EcoBioCAP esperience of exploring the whole chain from initial needs and expectations to end-products as well as to include both process and product innovation, NoAWs basic concepts also include some additional items, such as:

a) to add a multidimensional analysis to the conventional life cycle thinking of agro-waste management to address case studies representative of diverse territories (farming practices, pedo-climatic conditions, soil, seasonality, etc.),
b) to consider both consolidated and emerging technologies in a wide range of TRLs, and combination thereof, aiming at developing optimal combination of "conventional" end-products (such as biogas and soil improvers from anaerobic digestion) and innovative building blocks and bio-based materials as well.
c) by involving all agriculture chain stakeholders in a territorial perspective to ensure and accelerate the development of new business concepts and stakeholders platform for cross-chain valorisation of agro-waste on a territorial and seasonal basis.

More in detail, the NoAW's **scientific objectives are to:**

1) Further understand the territorial-seasonal-society nexus of agro-waste management and decipher the main hot spots on their environmental, safety and economic impacts,
2) Shift from a conventional a posteriori assessment to an eco-design approach applicable to the early stages of R&D,
3) Build a hybrid model based on territorial metabolism (TM) and LCA approaches to analyse agro-waste material flows, guide waste-resource recovery strategies and minimize impacts on water, air, soils,

4) Better understand conventional (benchmark) and innovative anaerobic digestion (AD) to increase energy and chemical recovery of diverse local waste resources,
5) Go beyond the limits of conventional green chemistry and develop breakthrough knowledge on agro-waste (including AD residues) molecular complexity and heterogeneity and on related converting cascading technologies into bio-active molecules, chemicals, building blocks and materials,
6) Get insights of the complexity of potentially new, cross-sectors, business clusters.

The technical objectives are to:

1) Develop on a territorial basis a range of methodologies on identification and assessment of the hot-points and potential solutions to reduce, eliminate and valorise agricultural waste,
2) Step up systemic approaches and decision support tools to design and assess agro-waste management strategies at appropriate scales and development stages with consistent guidance minimizing impacts on air, water, soil, quality and human safety,
3) Create a strategic AD core platform with a set of high added-value final products (i.e. biomethane, biohythane, alcohols, fertilizers, phenols, proteins, intermediates, biopolymers, composites etc.), including evaluation of possible upgrading of existing AD plants,
4) Develop tools to test business and collective marketing concepts, before extensive field studies.

The socio-economic and environmental objectives are to:

1) Set up a stakeholder knowledge platform (SKP) in view of implementing an extensive process of knowledge exchange in the whole agricultural waste production and consumption cycle (in relation with EIPs),
2) Build a pro-active structure able to shorten the gap between the local diverse actors involved, and fast track the use and acceptability of agro-waste management strategies,
3) Reduce the economic and environmental impact of agro-waste management with a specific focus on the preservation of soil agronomical and sanitary quality,
4) Target a zero-waste society by fully turning agro-waste feedstock into a portfolio of energy and chemicals able to substitute a significant range of non-renewable equivalents, with favourable air, water and soil impacts,
5) Demonstrate the potential for new business and employment creation through innovative dynamic cross-sector oriented clusters and a collective marketing approach including citizens.

The NoAW project is ready-to start start on October 1st, 2016.

Aknowledgements

The authors wish to thank all EcoBioCAP participants, whose work and results are briefly reported here. For more detailed information on specific activities and involved participants please refer to http://www.ecobiocap.eu/index.php. The authors also wish to thank all NoAW participants, whose work contributed to define the project aims, structure and planned activities.