Valorisation of agri-food residues for the food packaging sector: potentials and criticalities

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The beginning … 2001/2002

Working at the Institute of Oenology (later Oenology and Food Engineering)

PhD on Fungal Bioreactor for the treatment of off-gases

IDEA!

Working on the wine-making «wastes»

The wine-making residues

Source: www.cibercentros.jcyl.es

Stalks

Marc or Pomace

Lees

Effluents

Filtration residues

Valorisation of STALKS

- ✓Antioxidants → Food sector– cosmetic – pharmaceutical - materials
- ✓Sugars (Structural & not structural) → Food sector– fermentations - materials
- ✓Lignin → Antioxidants- materials
- ✓Cellulose → Materials - bioethanol

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Lignocellulosic Fractionation & Antioxidants Recovery ACID & BASIC HYDROLYSIS

Washing
Glu+Fru (%w/w)

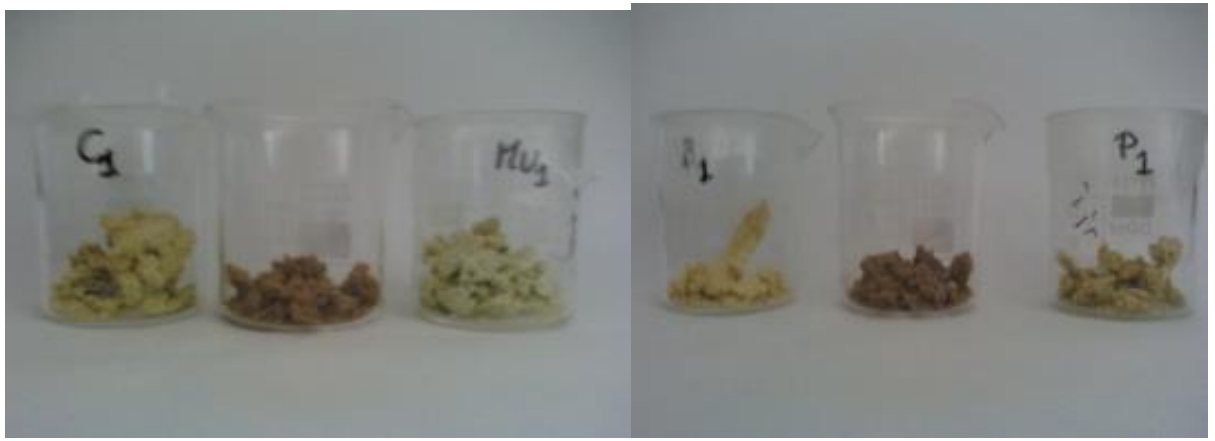
Chardonnay	Moscato	Muller	Barbera	Nebbiolo	Pinot nero
8.7±0.15	13.2±1.2	1.5±0.0	6.6±0.0	12.3±0.0	5.0±0.1

Liquor Acid
Xylose
Tot. phenols

Chardonnay	Moscato	Muller	Barbera	Nebbiolo	Pinot nero
5.3±0.0	4.1±0.3	5.3±0.1	6.6±0.1	3.3±0.2	5.9±0.1
1.2±0.0	1.2±0.1	1.3±0.0	1.0±0.0	1.3±0.0	1.2±0.0

Liquor Basic

Cellulose Residue



Lignocellulosic fractions to recover cellulose, sugars and lignin from other lignocellulosic residues with different processes

Valorisation of GRAPE POMACE

ANTIOXIDANTS RECOVERY

- Conventional Solvent extraction
- Microwave / US assisted extraction
- Cultivar & Vintage Influence
- Purification processes
- Encapsulation for aqueous media
- Encapsulation for lipid media
- Extract stability

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MARC COLLECTION

PRETREATMENT

Freezing, modified atmosphere, drying, drying, freeze-drying, seeds / skins separation, milling

EXTRACTION

Conventional with solvent, MAE, UAE, HP, supercritical, enzymes

CONCENTRATION

Crude concentrated liquid extract

DRYING / ENCAPSULATION

Crude powder extract

PURIFICATION

Purified concentrated liquid extract

DRYING / ENCAPSULATION

Purified powder extract

Valorisation of GRAPE POMACE
The ValorVitis project (2011/2018)

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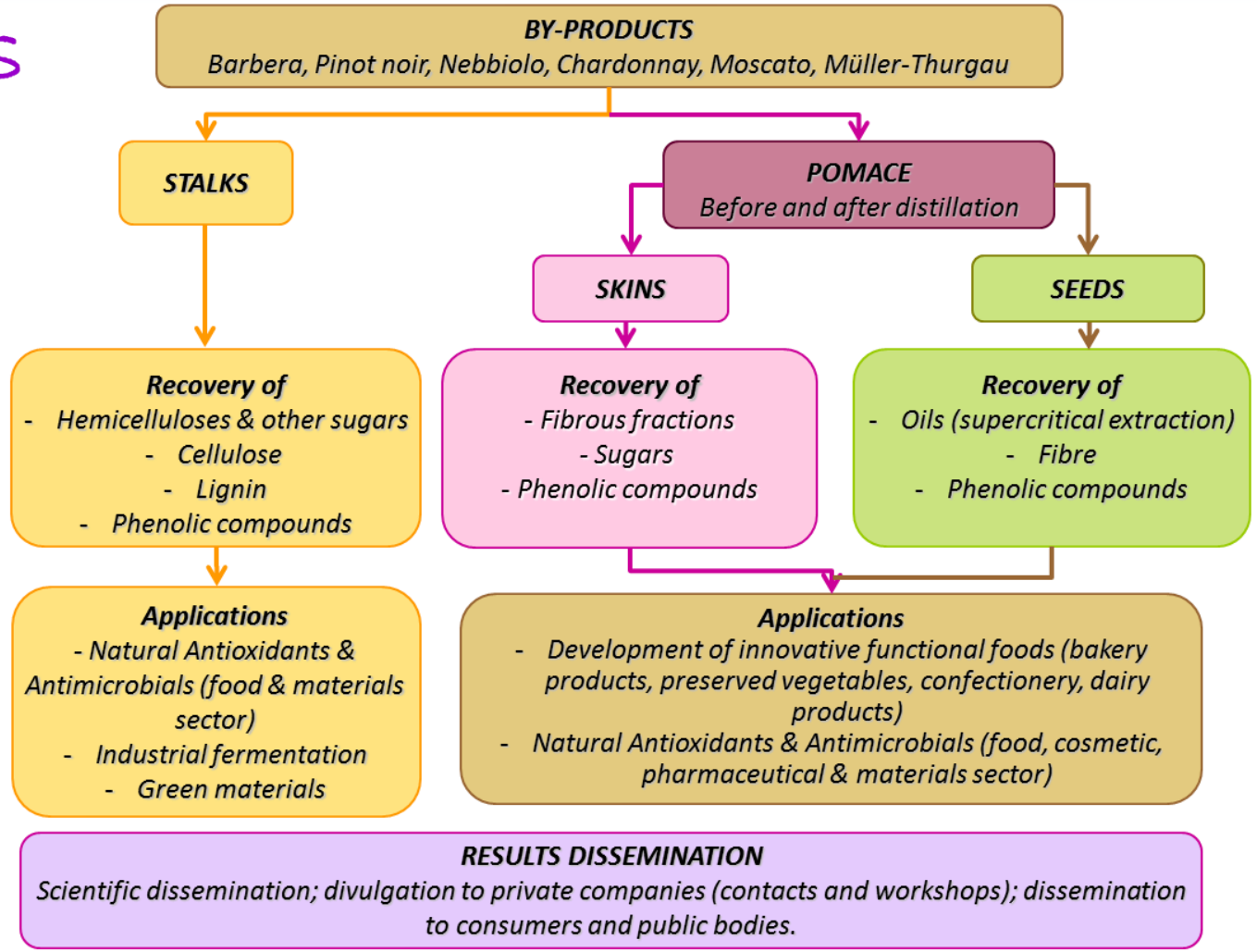
VALORVITIS

VALORVITIS 2.0

- The research results meet the market and the industry.
- Results validation
- Communication and promotion
- Business plan



PROGETTO Ager AGROALIMENTARE E RICERCA
FONDAZIONI IN RETE PER LA RICERCA AGROALIMENTARE

grant n° 2010-2222
grant n° 2017-2201

Valorisation of other residues the SusFoFlex project (2011-2015)

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SusFoFlex

SMART and SUSTAINABLE FOOD PACKAGING UTILIZING FLEXIBLE PRINTED INTELLIGENCE and MATERIALS TECHNOLOGIES

Agro-food by-products

UCSC
- Recovery of antioxidant extracts
- Complexation of antioxidants with Cyclodextrins for protection during polymer melt processing and service life

CEMITEC
- Cellulose-based bionanocomposite to add as fillers to polymers
- Immobilisation of antioxidant extracts on nano-silicates

SzTE
- Immobilisation of antioxidant extracts on Nanosilver particles

IK4 / TECCI
- PLA bio-polymer
- Addition of fillers produced by CEMITEC
- Addition of extracts produced by UCSC

REQUIMTE/ICETA
- (Nano)laminate coatings from food grade biopolymers from renewable and/or underexploited sources

ANDALTEC
- Information on processing needs
- Periodic testing of the developed materials
- (For final small scale production see WP8)

Grant agreement ID: 289829

SEVENTH FRAMEWORK PROGRAMME

BY-PRODUCTS SELECTION

Brewers' Spent Grains, Hazelnut shells, Wheat Straw, Orange Peels

ANTIOXIDANTS RECOVERY – ORANGE PEELS

- ***Complexation on nano-sylicates***
- ***Complexation on Silver nano particles***
- ***Addition into PLA plastic***
- ***Addition into edible coatings***

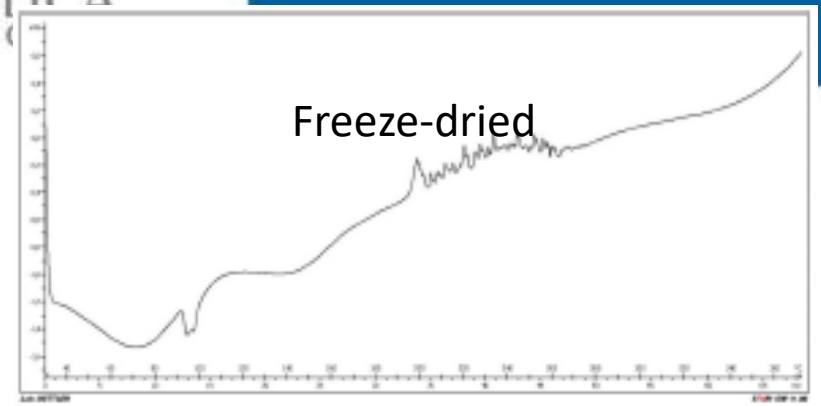
CELLULOSE RECOVERY - WHEAT STRAW

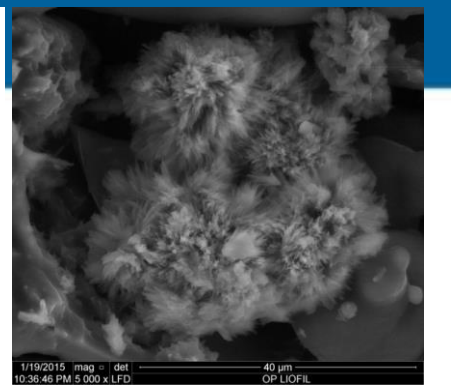
Production of bionanocomposites to be used as fillers for conventional and PLA based biopolymers

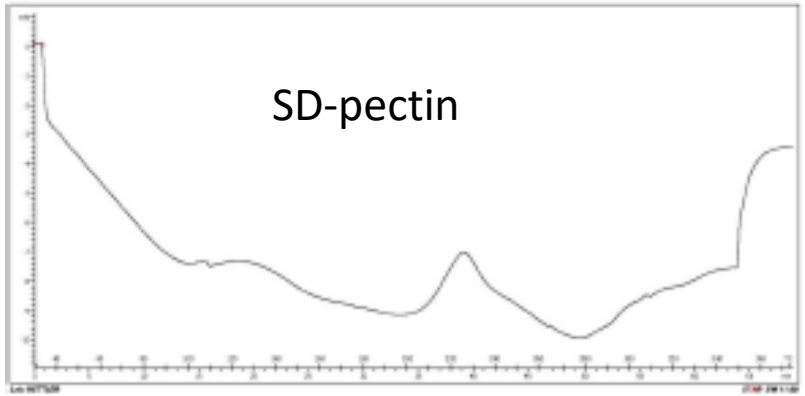
FRESH-CUT FRUITS PACKAGING

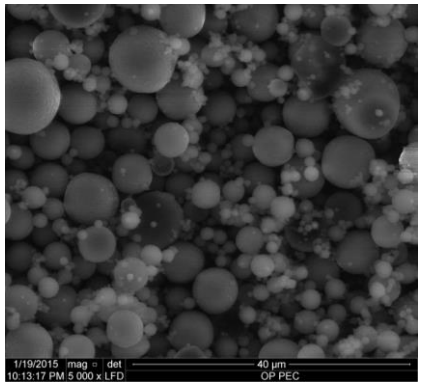
Orange peel extract modification - Drying

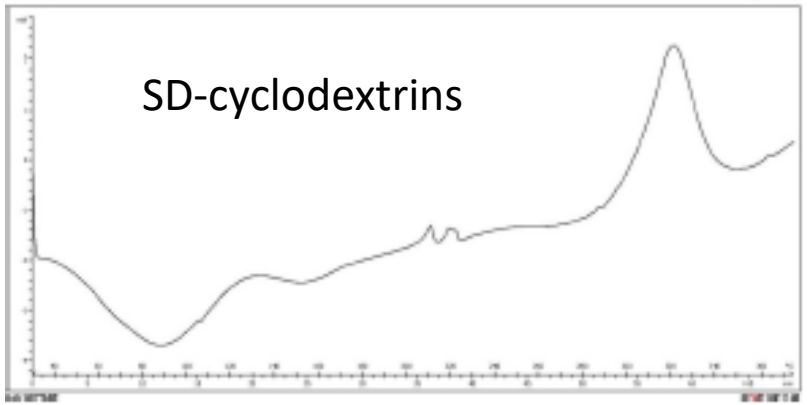
- Freeze-drying
- Spray-Drying with Citrus Pectin (Process Yield ≈ 70%)
- Spray-Drying with Cyclodextrins (Process Yield ≈ 70%)

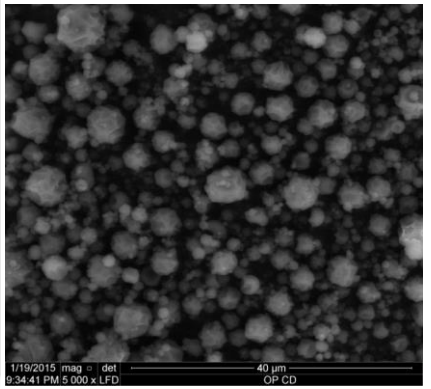


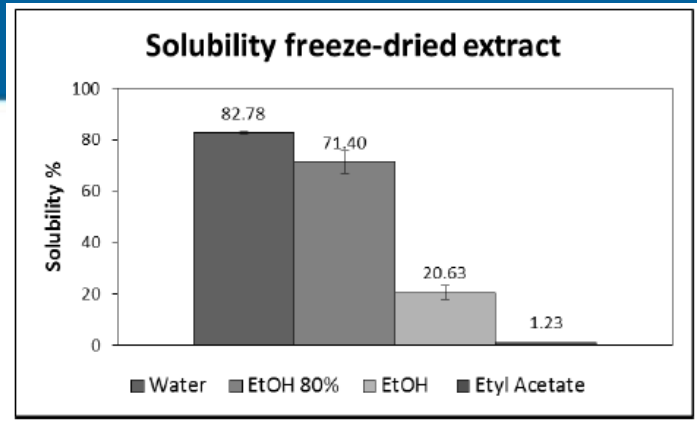


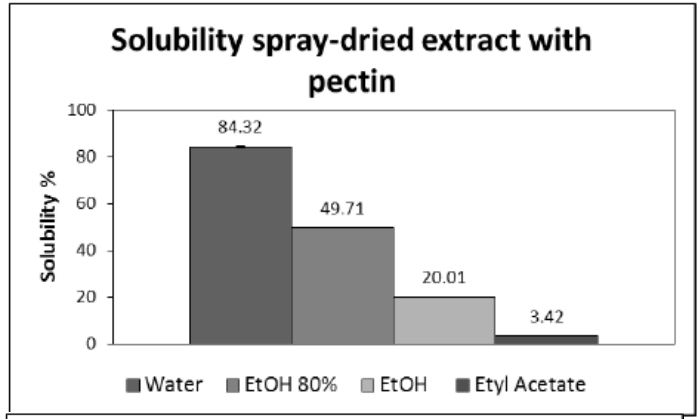


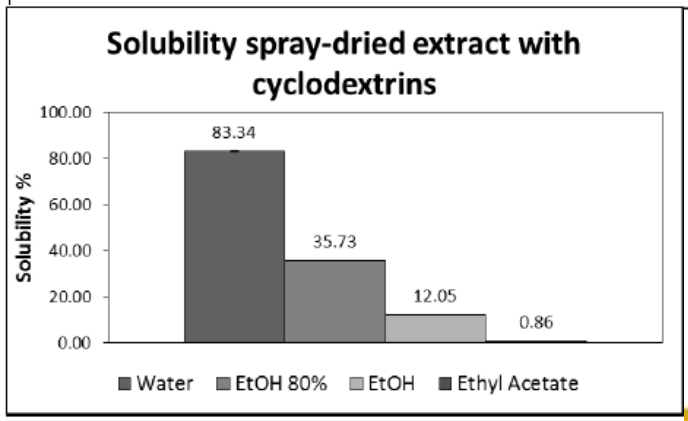












Orange peel extract modification - Purification

- Purification: adsorption on resin (Amberlite)
- Purified Freeze-dried extract up to 50 % phenols content (compared to 8 % of crude extract)

	OPE	EAA	WW	PE	Recovery %
Phenols content mg HE/L	5752.2	2019.4	n. d.	898.3	34.38
Naringin mg/L	13.87	n. d.	n. d.	5.41	85.80
Hesperidin mg/L	366.33	n. d.	n. d.	125.53	75.42
Citric acid g/L	71.01	66.48	10.44	n. d.	-
Glucose g/L	6.26	4.76	0.54	n. d.	-
Fructose g/L	6.83	5.16	0.57	n. d.	-
Sucrose g/L	7.82	5.50	0.70	n. d.	-
Ca mg/L	7.5	3.0	0.5	1.1	31.68
K mg/L	246.0	181.5	59.6	10.2	9.13
Na mg/L	10.0	13.2	2.9	2.5	55.22
Mg mg/L	8.6	5.1	0.8	1.2	30.43

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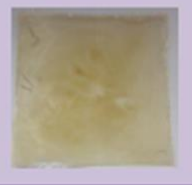
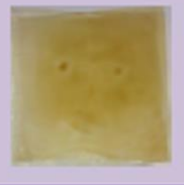
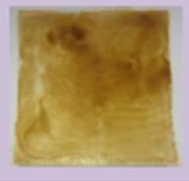
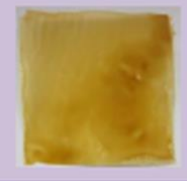
Orange peel extract modification & Environment…

To obtain 1 kg of Pectin-Sd-extract…

CRUDE EXTRACT PREPARATION		
INPUT	**OUTPUT**	**COMMENT**
104 kg fresh orange peels **3850 kg dry air** **468 MJ (9.35 kg methane)** **108 L Ethanol** **27 L Water**	19.5 kg (exhausted dry peels = solid waste) 26.2 kg CO_2 70.4 L Ethanol loss (vapor) 17.6 L Water vapor	The ethanol and water loss is probably less in an industrial scale process.
CRUDE EXTRACT PURIFICATION		
9.05 kg Resin **170 L NaOH 1 %** **1151 L Water** **60.5 L Ethanol** **30 L Acetone** **448 MJ (9 kg Methane)**	9.05 kg Resin 170 L Effluent NaOH 1 % 1196 L Water effluent 55 L Ethanol Loss (vapor) 7.4 kg solids waste from extract 25 kg CO_2	The 7.4 kg of solids removed from the extract will be distributed in the water effluent
SPRAY-DRYING		
0.443 kg Pectin **38.8 L water** **738.34 kWh**	0.26 kg solid waste 43.3 L water vapor 282 kg CO_2	The kWh have been calculated supposing the electric energy is produced via fuel combustion with a process efficiency of 35 %.

Orange peel extract modification - Complexation

- Complexation on nanoclays (100 $mg_{extract}/g$)
- Complexation on Silver nanoparticles
- Introduction into edible coating
- Introduction into PLA (freeze-dried, spray-dried with Cyclodextrins or pectin)

	PLA (HYCAIL) + % purified orange extract (FD)	PLA (HYCAIL) + % purified orange extract (PECTIN)	PLA (HYCAIL) + % purified orange extract (CD)
0.25% OE			
0.50% OE			
1.00% OE			
2.00% OE			

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Edible coatings

SPI
SOY PROTEIN ISOLATE

HM
CITRUS PECTIN

PRODUCTION OF AN ANTIOXIDANT / ANTIMICROBIAL EXTRACT

HESPERIDIN (reference)

SELECTION OF POLYMERIC MATERIAL FOR EDIBLE COATING

PECTIN

FIRST TRIALS ON FRESH-CUT APPLES

COMPARISON ORANGE EXTRACT – HESPERIDIN

EDIBLE COATINGS ON FRESH-CUT APPLES

SHELF-LIFE TEST

- *Colour, Texture, Microbiological quality*

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Results – *EDIBLE COATINGS – POLYMER SELECTION*

MICROBIAL GROWTH after 5 days

TREATMENT	Mesophilic count	Psychrotrophic count	Moulds
NO FILM	nd	2.00E+05	2.00E+04
ASCORBATE	nd	2.25E+05	2.58E+06
PECTIN + OPE	nd	nd	nd
SPI + OPE	nd	7.57E+05	7.97E+05
NO FILM	4.20E+04	2.32E+05	3.99E+05
ASCORBATE	8.93E+04	8.525E+04	1.16E+05
PECTIN + OPE	nd	nd	nd
PECTIN + HE	nd	7.33E+03	1.10E+04

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Results – *EDIBLE COATINGS – POLYMER SELECTION*

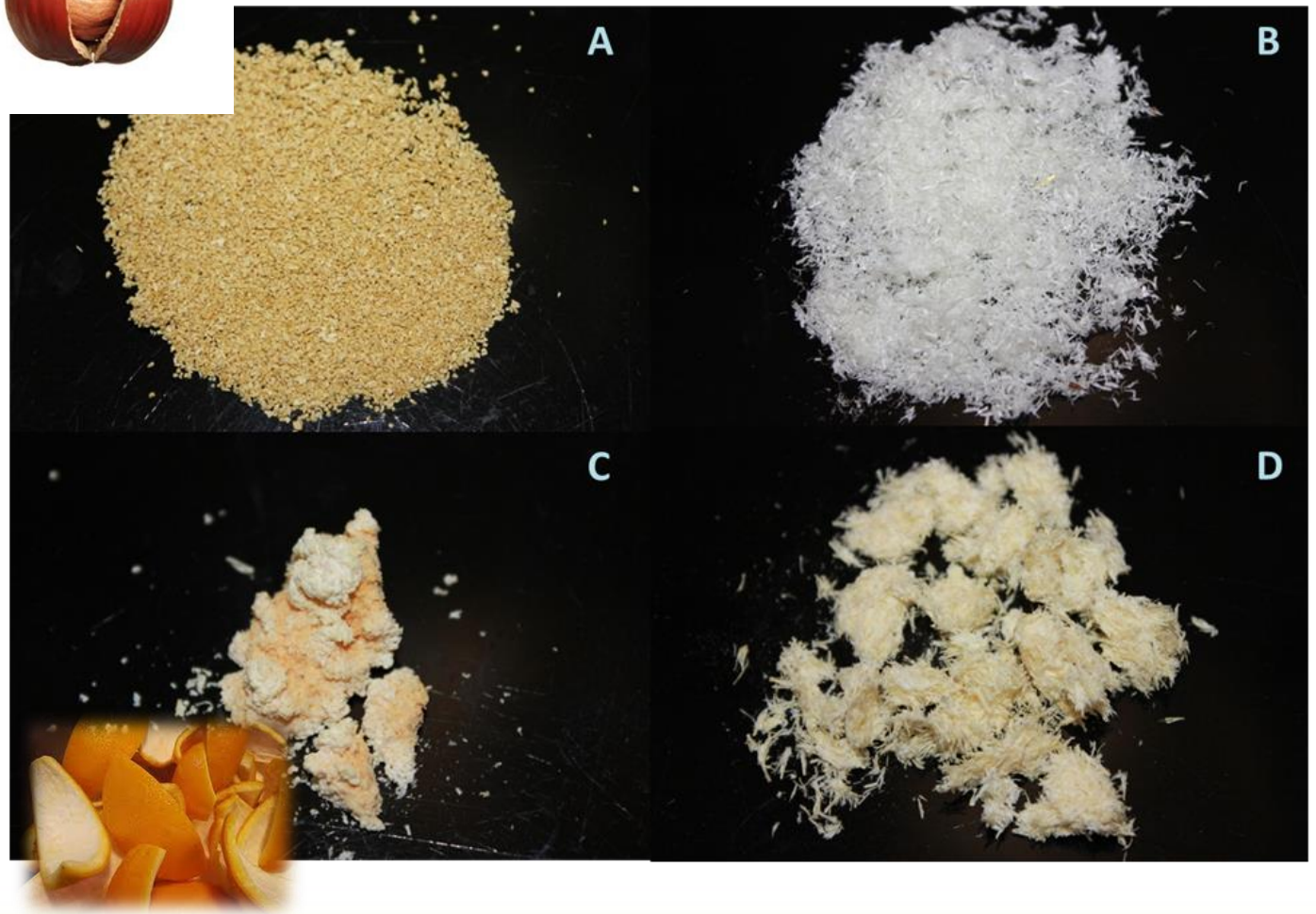
COLOUR

	Day 0	Day 2	Day 5
NO FILM	#D0BF78 (208,191,120)	#CEBC81 (206,188,129)	#C9AF6C (201,175,108)
ASCORBATE	#D3CC99 (211,204,153)	#D3CB94 (211,203,148)	#CFC68E (207,198,142)
PECTIN + OPE	#D2C280 (210,194,128)	#CFBA7A (207,186,122)	#CFB576 (207,181,118)
SPI + OPE	#C2B06C (194,176,108)	#CBAE6D (203,174,109)	#CCAE6D (204,174,109)

Cellulose Recovery from by-products

Component	Wheat Straw	Hazelnut Shells	Orange Peels	Brewers' Spent Grains
Cellulose residue yield (g/100 g_{dm})	16.91 ± 2.72	41.17 ± 0.23	6.78 ± 0.11	5.66 ± 0.37
Cellulose content (%)	84.07 ± 1.80	37.01 ± 1.15	56.11 ± 0.43	61.34 ± 1.63
Cellulose recovery (%)	44.70 ± 0.92	58.68 ± 7.99	24.91 ± 1.84	35.84 ± 6.28
Hemicellulose content (%)	2.10 ± 0.12	2.58 ± 0.09	1.28 ± 0.09	1.57 ± 0.08
Acid insoluble lignin (%)	12.43 ± 0.24	27.99 ± 2.72	13.46 ± 1.17	16.48 ± 2.25

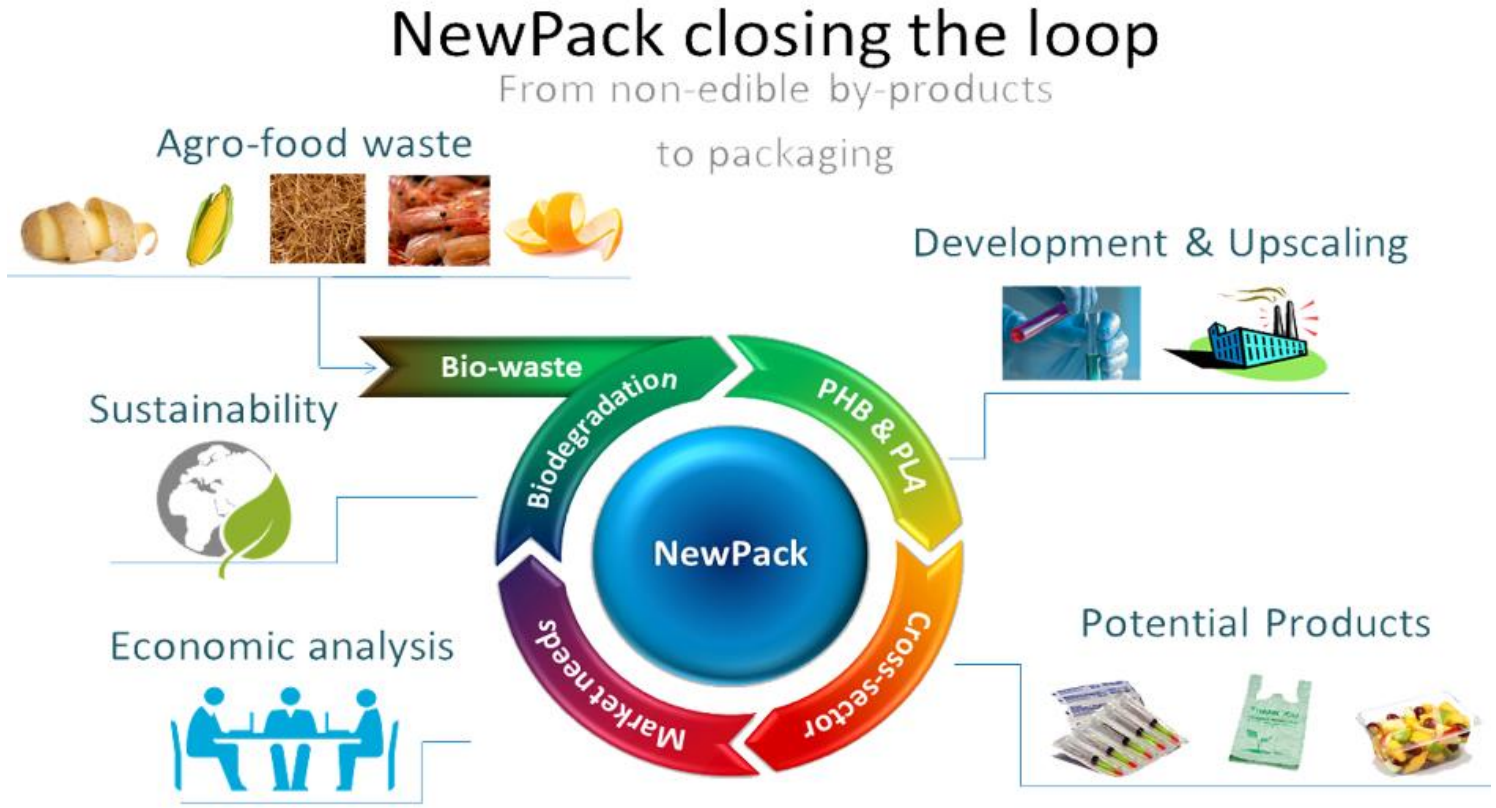
Cellulose Recovery: by-product Selection



NewPack

New BioBased Film for Packaging

The overall objective of NewPack (H2020, BBI-JU project) is to develop new food packaging materials based on PLA/PHB mixtures. PHB produced from sweet corn residues and potato peels. Nanowhiskers additives from wheat straw. Nanochitin from fish wastes. Functional coatings with natural extracts.



This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792261

- **Cellulose isolation and additivation**

MICROCRYSTALLINE CELLULOSE RECOVERY

NANOCELLULOSE ISOLATION

INCORPORATION

This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792261

- **Natural extracts with antimicrobial and/or antioxidant functionalities**

FROM BY-PRODUCTS

CHARACTERISATION

COMMERCIAL EXTRACTS

SELECTION

INCORPORATION

This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792261

Valorisation of grape residues, ReMarcForFood Project (2017-2019)

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BY-PRODUCT COLLECTION

On wet or dry biomass. Medium composition to be optimised

SUBSTRATE FOR FUNGAL GROWTH

DRYING, SIEVING, CLEANING AND GRINDING

ENZYMATIC TREATMENT

New tailored enzymes

Before or after drying? Process parameters (enzyme type, concentration, water-to-solid ratio, homogenisation, t & T to be optimised

Commercial enzymes

Protein enriched edible mushrooms

EXTRACTION OF BIOACTIVES

High-Fiber, Low-Sugar flour

DEVELOPMENT OF INNOVATIVE FUNCTIONAL FOODS AND DIETS

HYDROLYSED High-Fiber, Low-Sugar flour with improved fiber composition and bioactives bioavailability

MARIE CURIE ACTIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 778388.

Fondazione CARIPLO

ReMarcForFood has received funding by Fondazione Cariplo (2016-0740 grant)

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Valorisation of different residues, The Fodiac Project (2018-2021)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 778388.

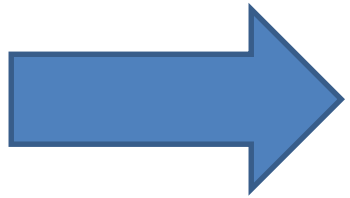
FODIAC
Food for Diabetes And Cognition

The overall R&I objective of FODIAC is to develop an integrative dietary solution to tackle diabetes and the associated impairment of the cognitive function among the elderly by the development of bioactive ingredients, and functional foods and diets.

By-product?

EU waste management law (Directive 2008/98/CE) specified that a by-product is "*a result from a production process that was not the primary aim of that process*" and that "*unlike waste, it must be able to be used afterwards*".

Criteria to be satisfied at the same time …



To be a (non waste) by-product

Criteria Indicated by the Commission in a Communication to the Council and the European Parliament on the Interpretative Communication on waste and by-products

- Must originate from a production process without being the main production aim
- Must be usable again in the same production process or in a next production or utilization process
- Must be directly re-usable without any further treatment outside normal industrial practice
- Must have a market value
- The final use should be integral and without negative impacts on neither human health, nor environment.

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What does it miss???

Sustainability

Whole chain

Scale-up

Local

By-product according to law

Process modelling & Control

Green Processes

Nano-materials and legislation

Novel foods & ingredients

New functionalities

Good tasting

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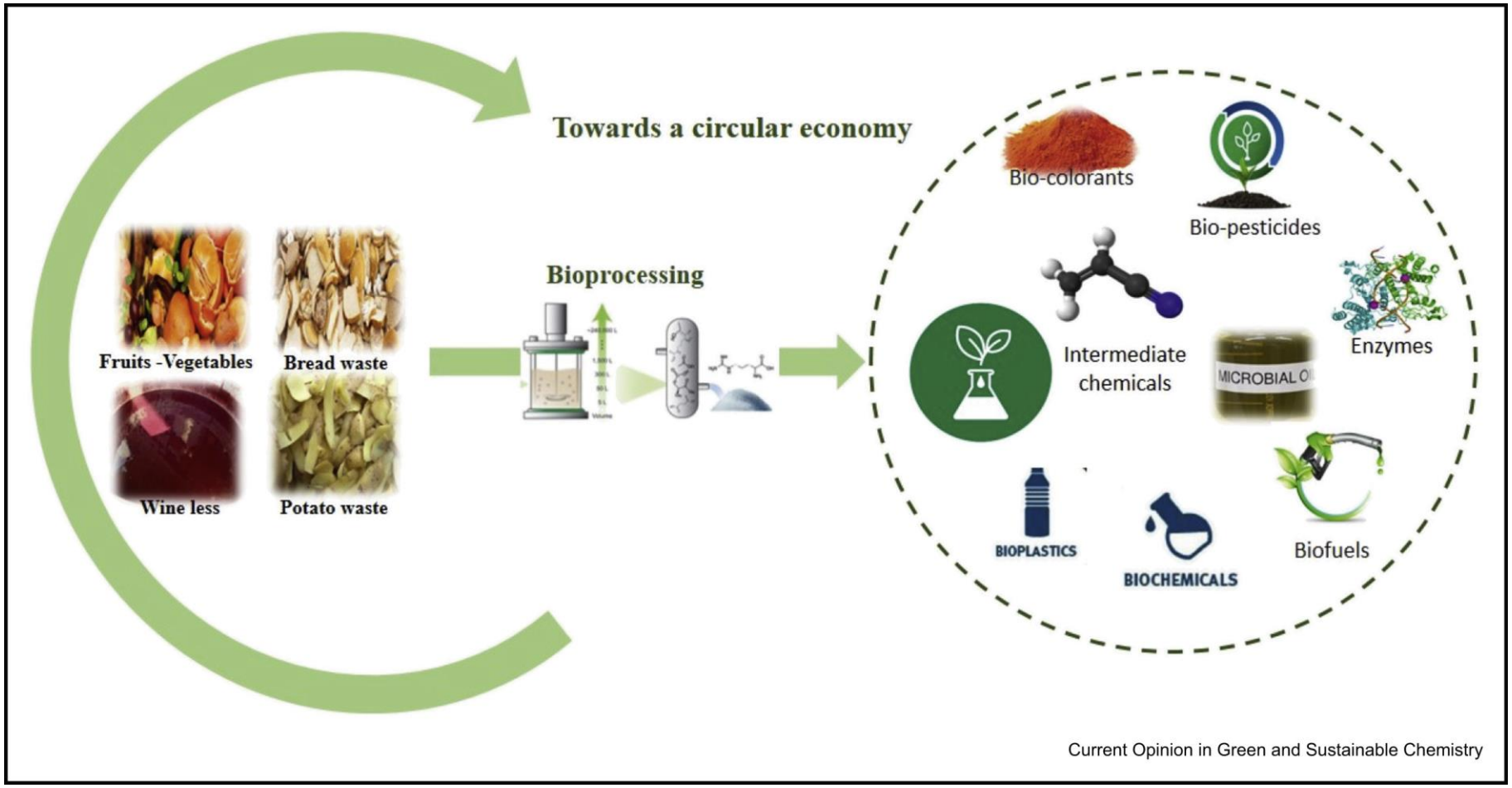
CONCLUSION…



Maina et al., 2017, 8, 18-23.