



From Plant Waste to Fruit Protection: The PLAMINPACK Approach

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UNIVERSITÀ DI PISA



Renewability, compostability and recyclability of packaging are becoming more and more important because of the necessity of decreasing its burden on environment.

Renewability



reduced greenhouse gases emissions

Compostability



circularity and soil quality

Recyclability



as longer as possible storage of carbon
in products before their composting

Multifunctional, Bio-EcoCOmpatible Materials (MBEM) lab

<https://it.linkedin.com/in/mbem-lab-unipi-b397a8261>

Prof. Andrea Lazzeri

Maria-Beatrice Coltelli

Laura Aliotta

Vito Gigante

Bianca Dal Pont

Francesca Cartoni

David Conti

Roberto D'Ambrosio (IPCF-CNR)

Oussama Bat

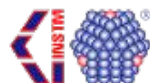
Noemi Onesto

Michele Monti





Concluded EU projects

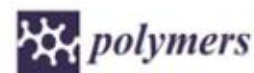


Novel packaging films and textiles with tailored end of life and performance based on bio-based copolymers and coatings

- PLA/PBSA blends to obtain films and bran reinforced composites
- Home-compostable
- Recyclable



ECOFUNCO project: Eco sustainable multifunctional biobased coatings with enhanced performance and end of life options



Article

Antimicrobial and Gas Barrier Crustaceans and Fungal Chitin-Based Coatings on Biodegradable Bioplastic Films

Luca Panariello ^{1,2}, Maria-Beatrice Coltelli ^{1,2,*}, Ahdi Hadrich ³, Francesca Braca ⁴, Stefano Fiori ⁵, Amit Haviv ⁶, Filip Miketa ⁷, Andrea Lazzeri ^{1,2,8}, Andreas Staebler ⁹, Vito Gigante ^{1,2} and Patrizia Cinelli ^{1,2,*}

Applied onto bioplastic thermoformed prototypes



scientific reports



OPEN

Characterization of chitin and chitosan derived from *Hermetia illucens*, a further step in a circular economy process

Micaela Triunfo^{1,4}, Elena Tafi^{1,6}, Anna Guarnieri^{1,6}, Rosanna Salvia^{1,2,5}, Carmen Scieuzo^{1,2}, Thomas Hahn³, Susanne Zibek³, Alessandro Gagliardini⁴, Luca Panariello⁵, Maria Beatrice Coltelli⁵, Anela De Bonis¹ & Patrizia Falabella^{1,2,5}



Prof. Patrizia Falabella, UNIBAS

Chitin is a by-product of the *Hermetia illucens* rearing plant

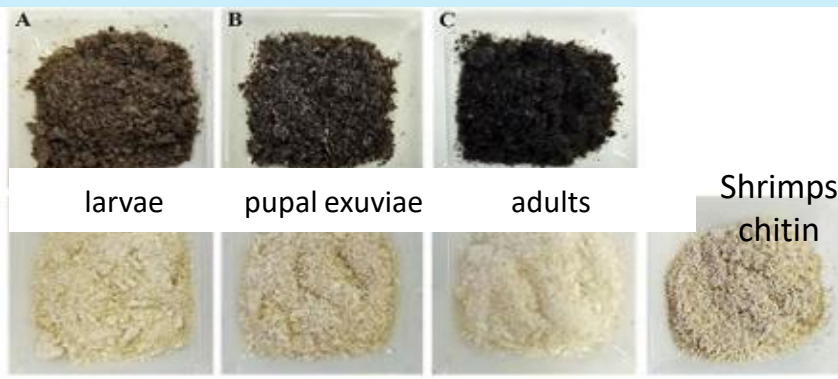
scientific reports

OPEN

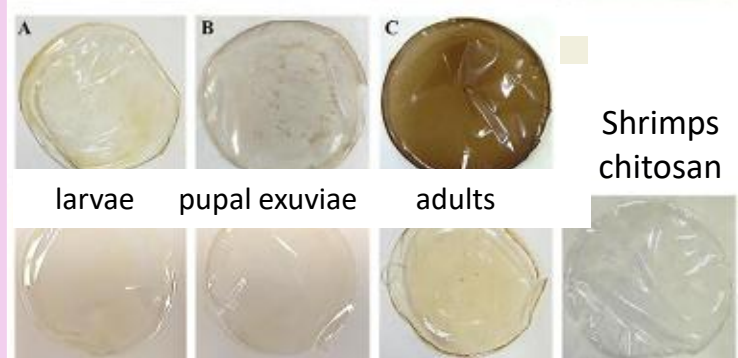
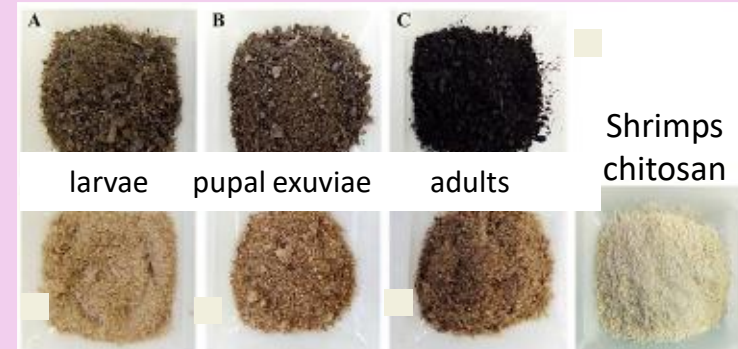
Characterization of chitin and chitosan derived from *Hermetia illucens*, a further step in a circular economy process

Micaela Triunfo^{1,6}, Elena Tafi^{1,6}, Anna Guarnieri^{1,6}, Rosanna Salvia^{1,2,10}, Carmen Scieuzo^{1,2}, Thomas Hahn³, Susanne Zibek³, Alessandro Gagliardini⁴, Luca Panariello⁵, Maria Beatrice Coltelli⁵, Angela De Bonis¹ & Patrizia Falabella^{1,2,10}

CHITIN



CHITOSAN

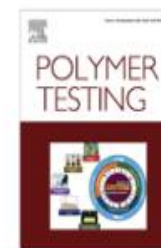


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A comprehensive characterization of *Hermetia illucens* derived chitosan produced through homogeneous deacetylation

Micaela Triunfo¹, Anna Guarnieri¹, Dolores Ianniciello², Maria Beatrice Coltelli³, Rosanna Salvia⁴, Carmen Scieuzo⁵, Angela De Bonis¹, Patrizia Falabella¹ [Show more](#)

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Chitin and chitosan materials from black soldier fly (*Hermetia illucens*): An insight onto their thermal degradation and mechanical behavior linked to their copolymeric structure

Maria Beatrice Coltelli¹, Vita Gigante², Luca Panariello³, Laura Aliotta⁴, Carmen Scieuzo⁵, Patrizia Falabella⁶, Andrea Lazzeri⁷ [Show more](#)

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Food waste problem

Food waste is another serious global problem: approximately one-third of global food production is wasted every year, accounting for 8–10% of greenhouse gas emissions and the loss of natural resources such as water, energy, and soil.



Yearly average global food loss and waste

1/3 of the world's food

1.3 billion tons

1 trillion US dollars

 **45 %** of all fruit and vegetables

 **35 %** of all fish and seafood

 **30 %** of all cereals

 **20 %** of all dairy products

 **20 %** of all meat and poultry

The Mediterranean region is particularly vulnerable to the effects of climate change (loss of biodiversity, water scarcity, and soil degradation) and experiences very high levels of food waste.

Functional
packaging for
protection of
foods



Antioxidant and
anti-microbial
properties



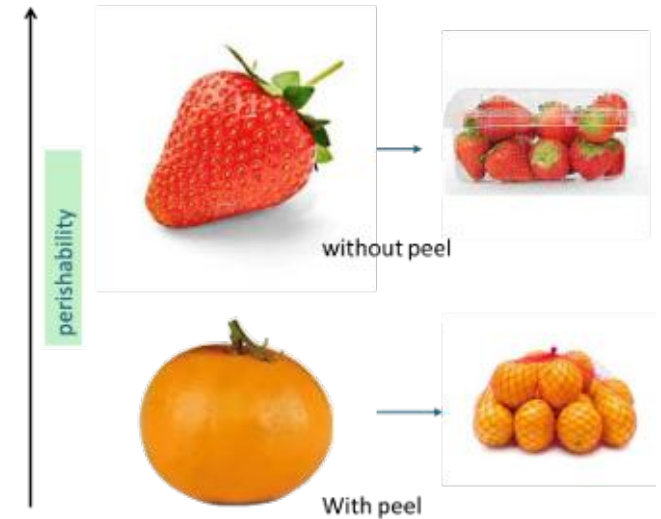
Functional
packaging for
increasing
recyclability

Issues of the Mediterranean area

- Excessive waste of Mediterranean perishable foods
- Not utilized agro-waste of plants
- Need of smart, «biomimetic» and biocircular packed fruits

Biopolymer matrix composites with filler derived from fruit cultivation waste to:

- valorize the agro-waste
- improve rigidity
- improve biodegradability
- reduce production costs



Use of extracted anti-oxidants and anti-microbial biopolymers from insects to add specific properties

PLAMINPACK

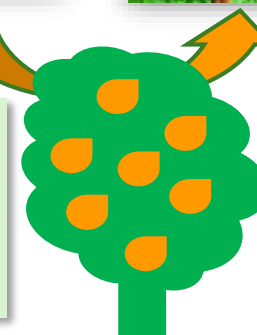


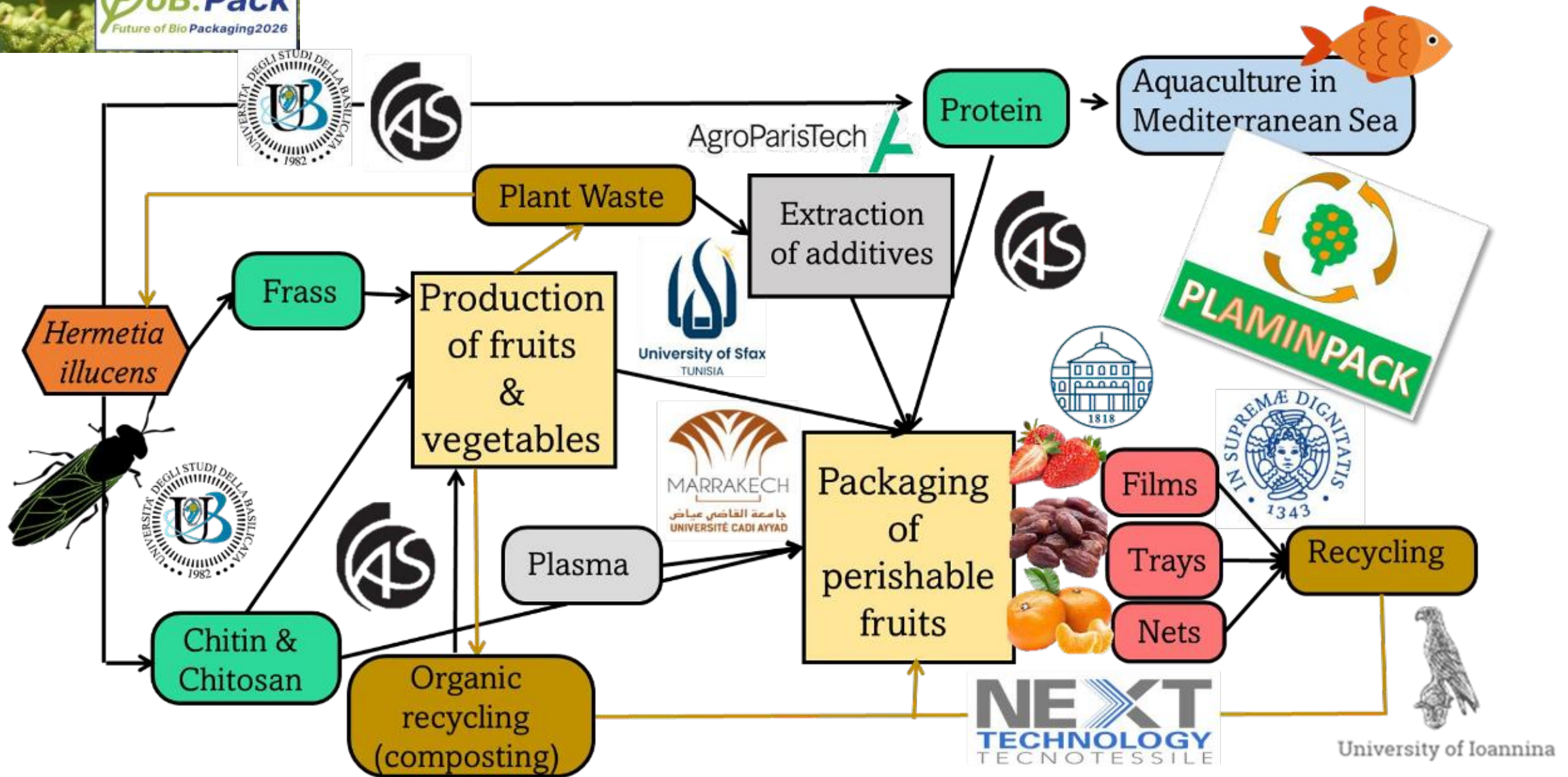
*Mediterranean
perishable foods*

PLAnt-based
antiMlcrobial
aNd circular
PACKaging for
plant products



*AMIN in Arabic means safe: the best
protection for its fruits lies in the plant*

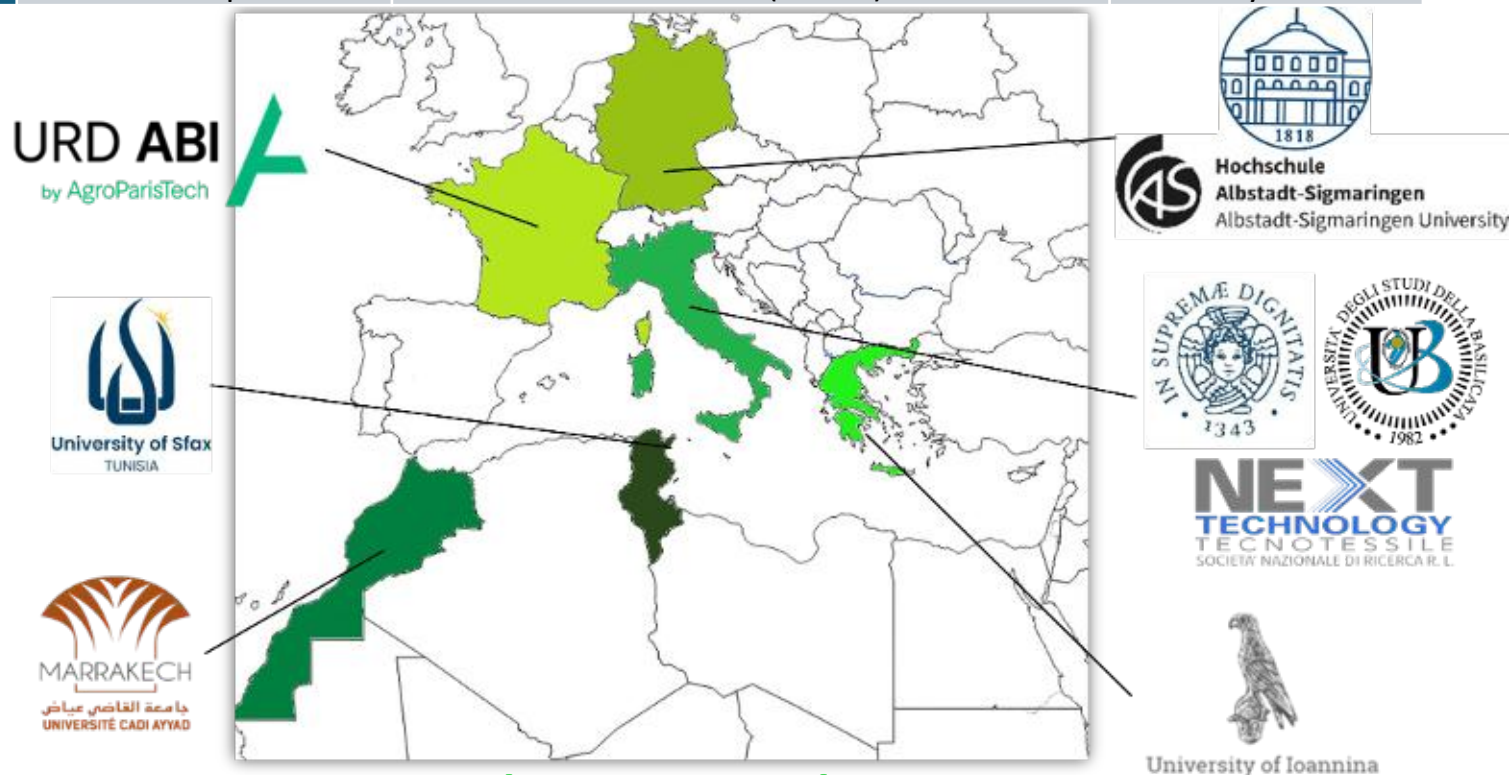






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4 Partner	Patrizia Falabella	Università degli Studi della Basilicata (UNIBAS)	Italy
5 Partner	Florent Allais	AgroParisTech (APT)	France
6 Partner	Hajer Ben Hlima	Sfax University (SFAX)	Tunisia
7 Partner	Ioannis Konstantinou	University of Ioannina (UOI)	Greece
8 Partner	Markus Schmid	Albstadt-Sigmaringen University (ASU)	Germany
9 Partner	Christian Krupitzer	Universität Hohenheim (UHOH)	Germany

9 PARTNERS FROM 6
DIFFERENT COUNTRIES

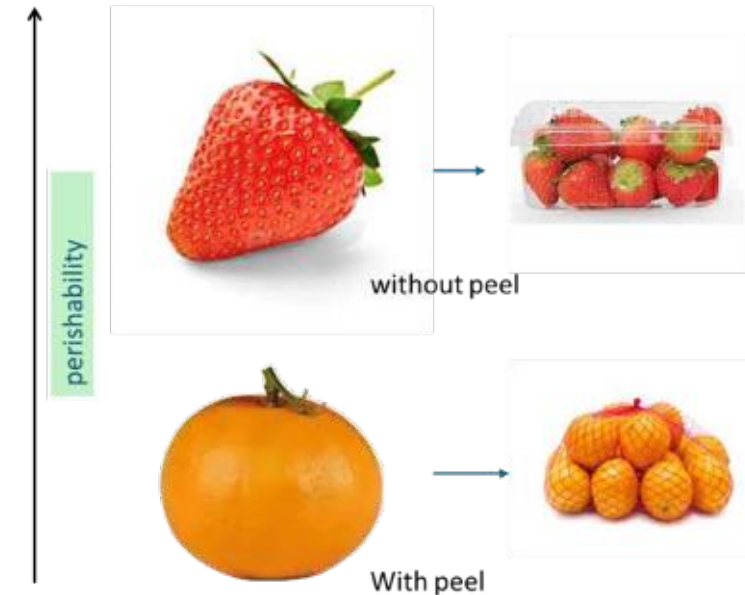


www.plaminpack.com

The packaging materials: Unipi role

WP2

- Development and selection of materials for films, trays and nets;
- Production of prototypes of film, trays and net.



Raw materials from strawberry, dates and tangerins plants



Strawberry plant

Pisa, centro Avanzi



Date palm (Boufeggous)
-10 Kg grinded Leaves

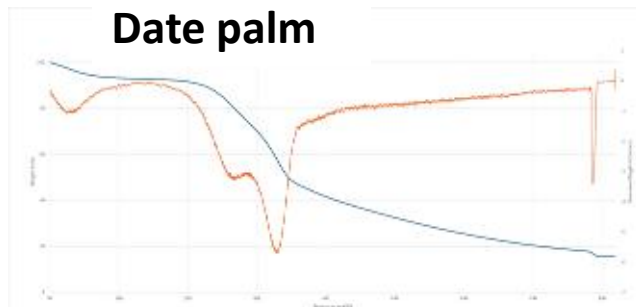


Tangerine plant (Nadorcott)
-16 Kg grinded (Leaves /
Stem / Leaves +Stem)

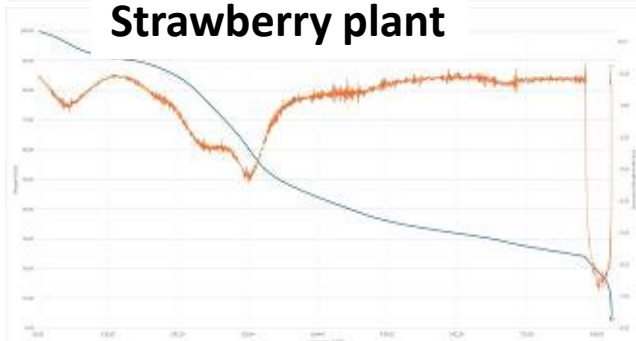
Raw powders from strawberry, dates and tangerins plants



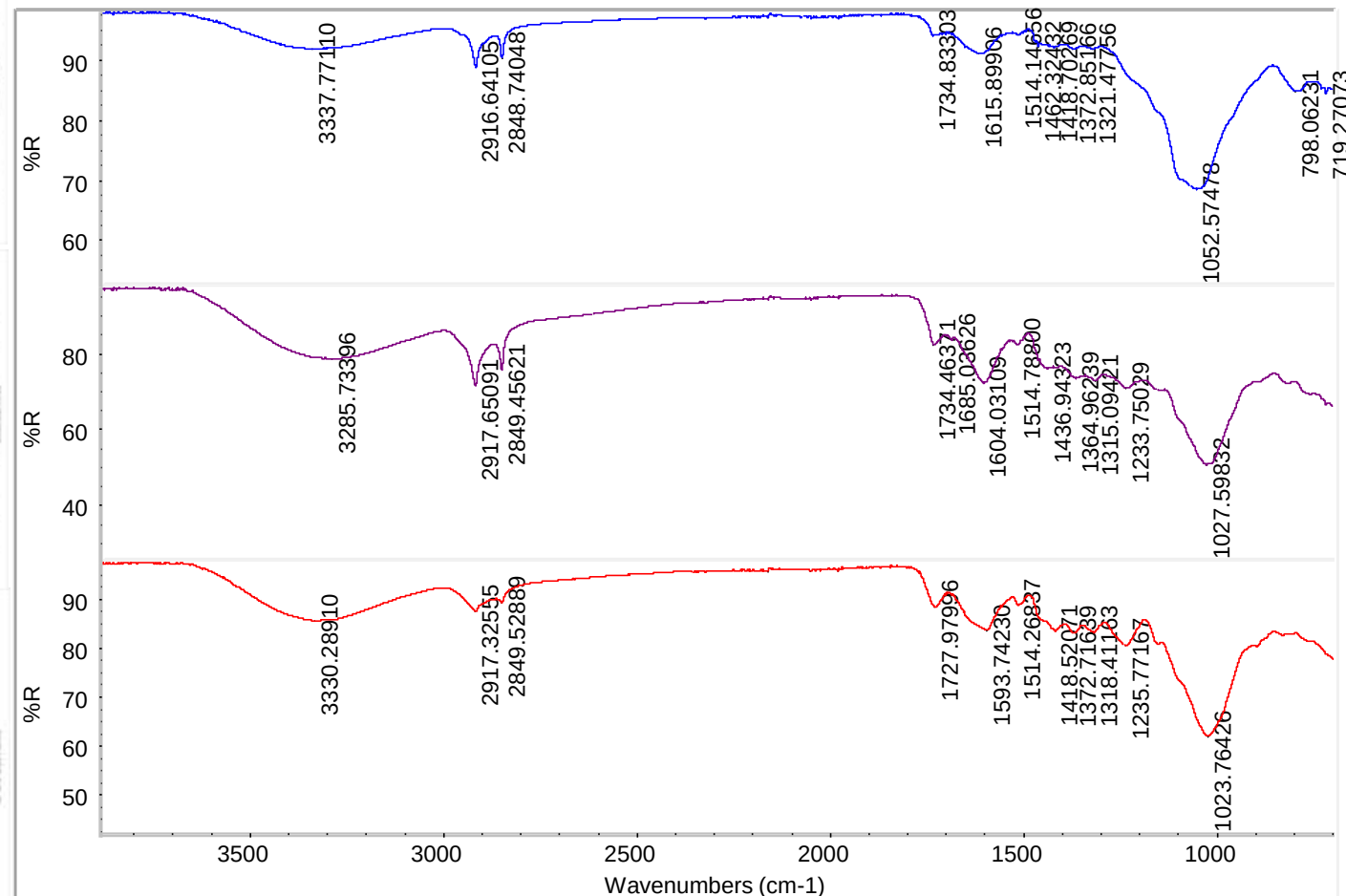
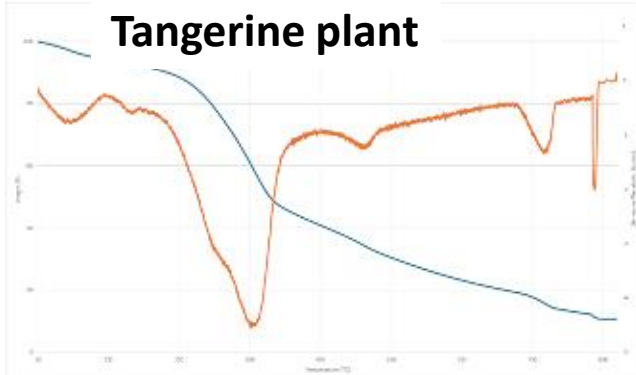
Date palm



Strawberry plant

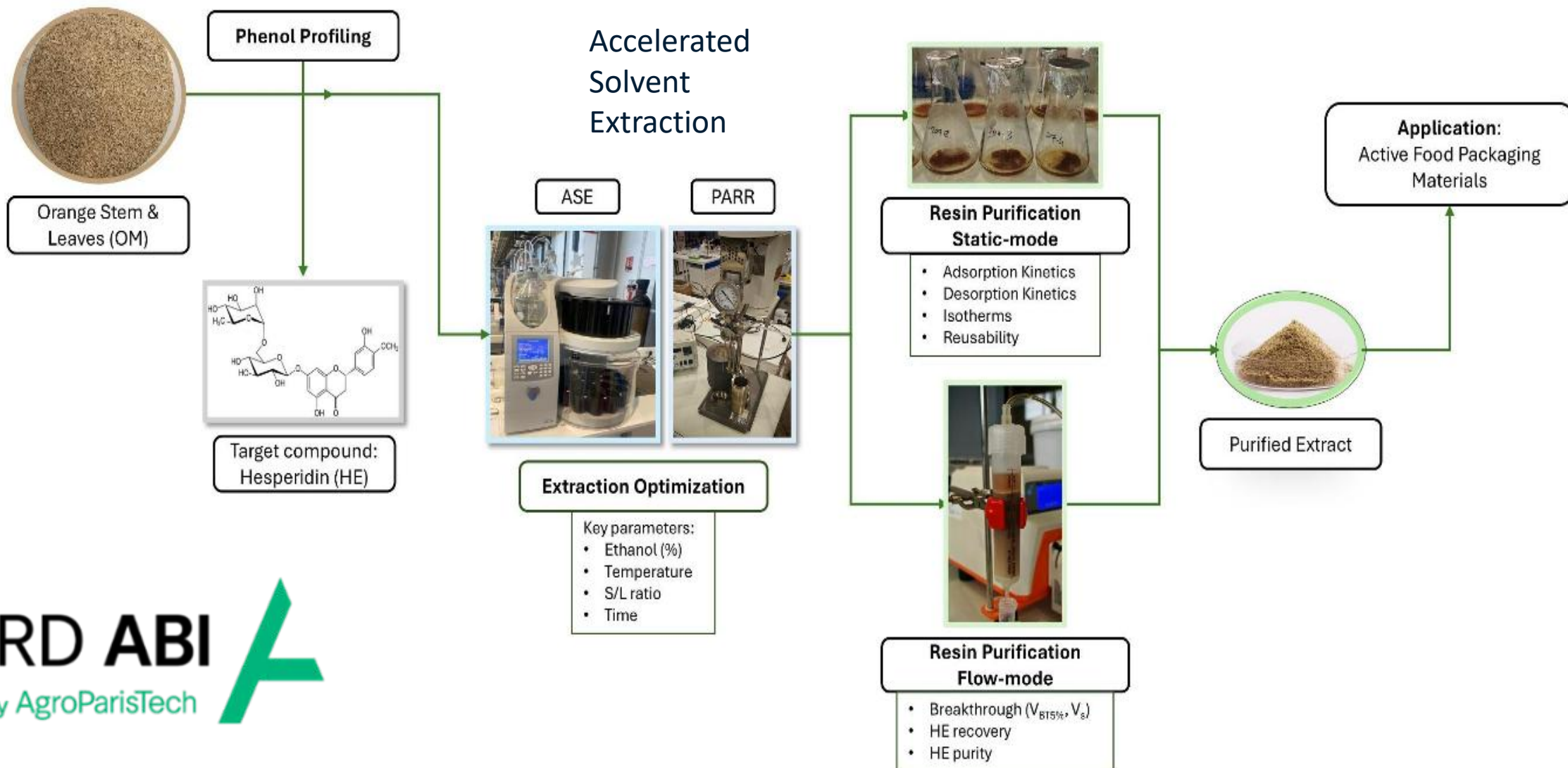


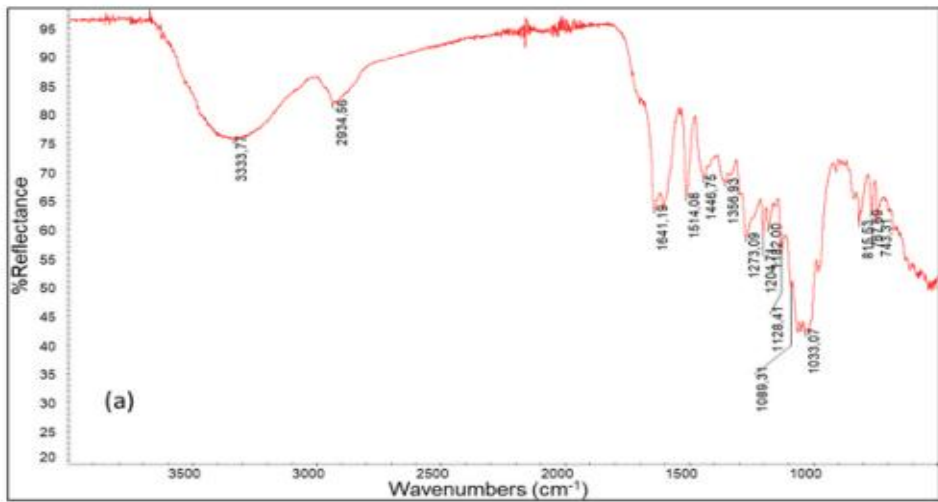
Tangerine plant



Date plant waste showed the highest thermal stability but a very irregular and coarse fibrous structure. Infrared ATR spectra suggested diversification in aromatic/phenolic content of powders.

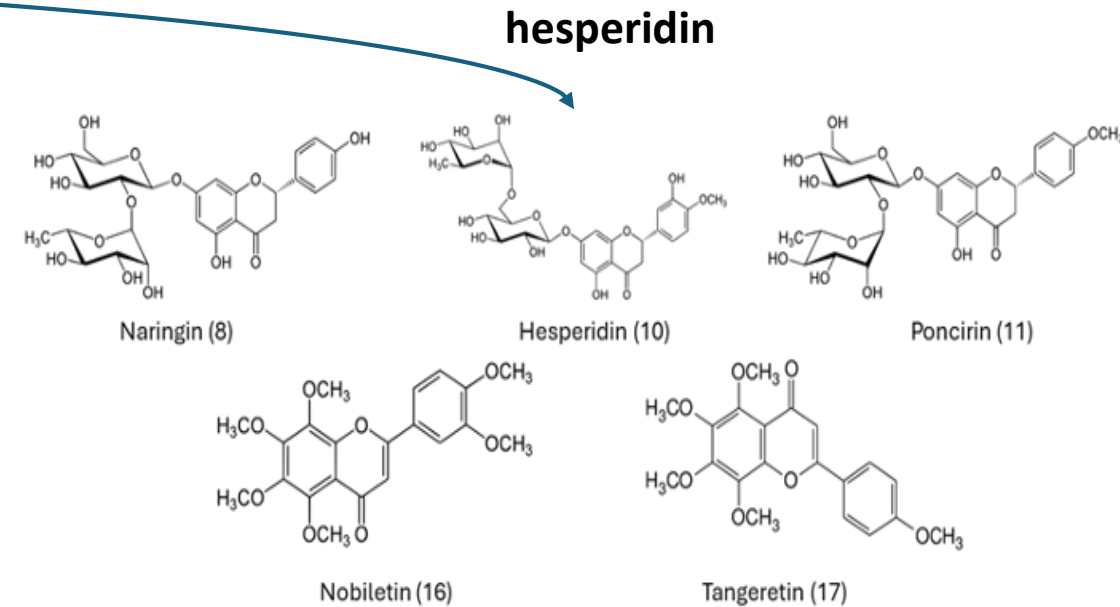
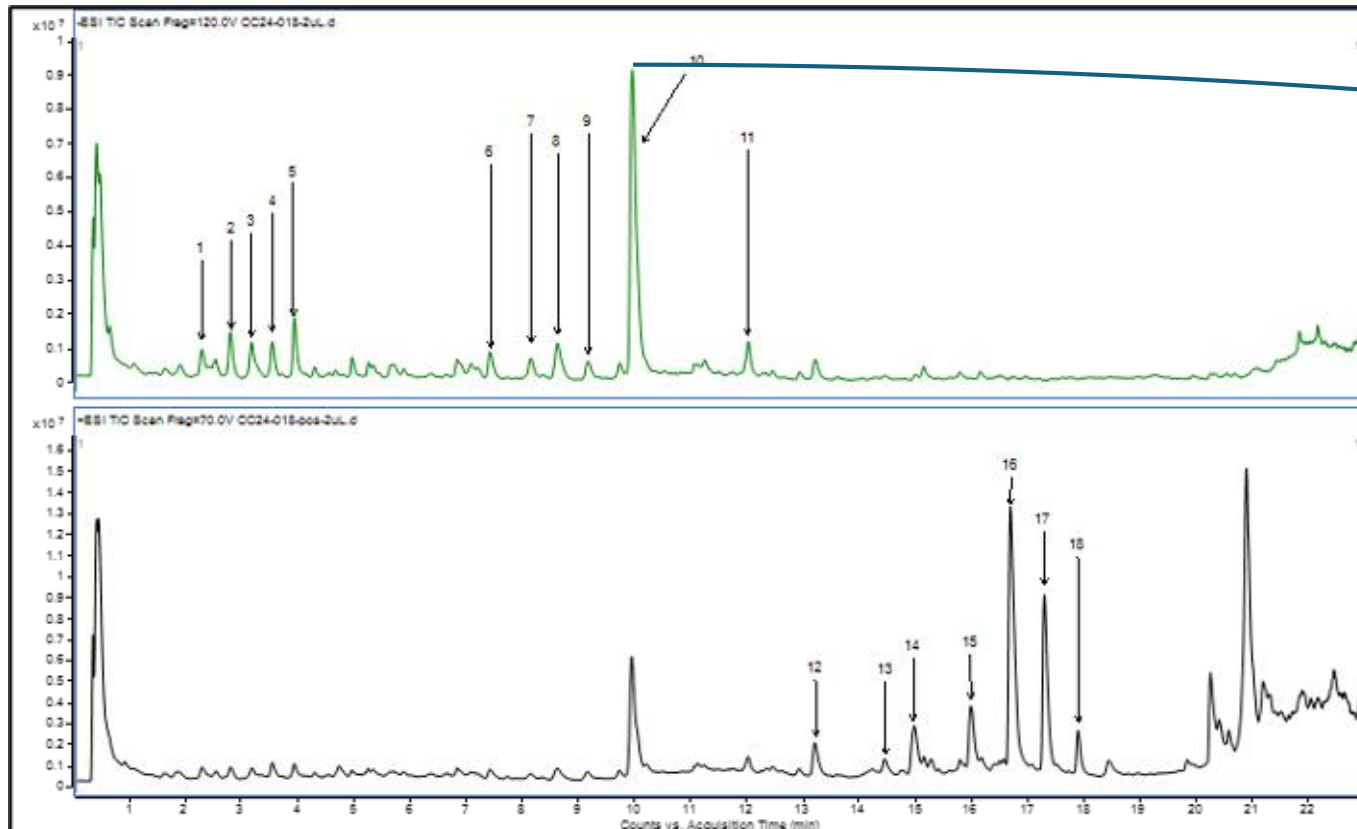
Tangerine tree based waste



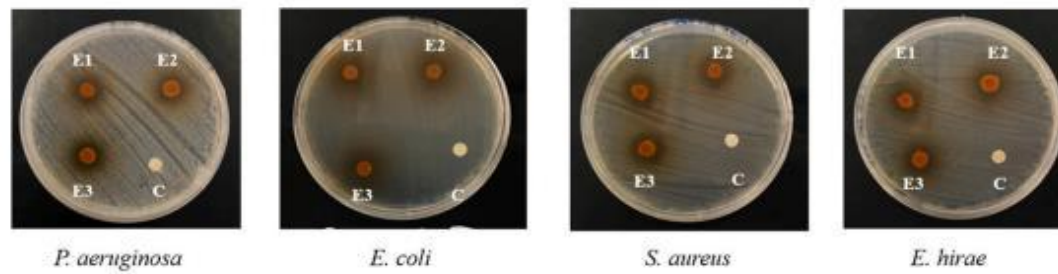


This band thus suggests the presence of sugars or other polyphenolic compounds in the Hesperidin-based extract. Hesperidin is about 10 mg/gDM and TPC is 20 mg/gDM.

The weight fraction of extracted material consists of about 10%, hence about 90% is the residual fraction



LC-MS/MS analysis for polyphenol profiling



purified extract has a bacteriostatic effect on the four strains studied:

Fig. 14. Inhibition zones observed in the disk diffusion test of the purified extract from *Citrus reticulata* against the tested bacteria (E: Purified extract, C: control 15% DMSO-EtOH).

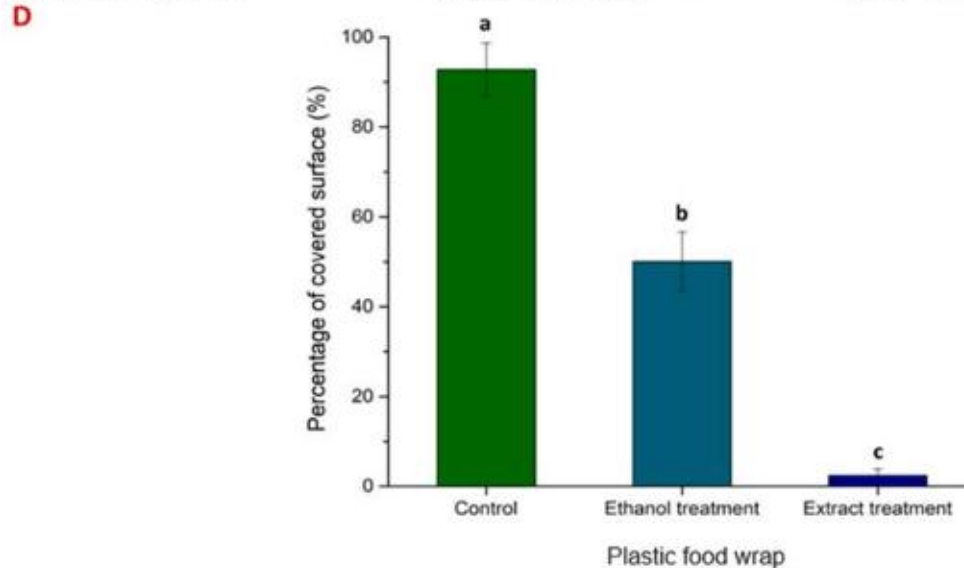
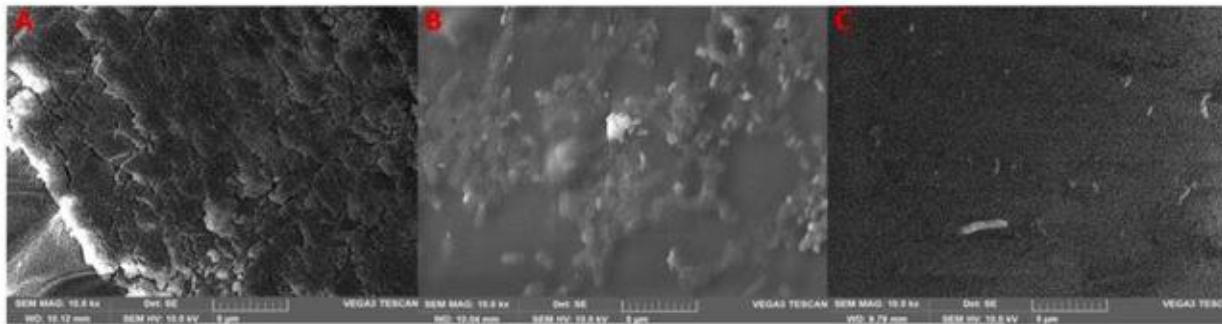


Fig. 15. Bacterial adhesion on (A) the untreated food wrap, (B) EtOH-treated food wrap and (C) purified *C. reticulata* extract-treated food wrap, and (D) the percentage of surface covered by bacteria.

the extract treatment considerably inhibited the cells' attachment, where the percentage of covered surface was lower than 5%

Industrial Crops & Products 244 (2026) 123189



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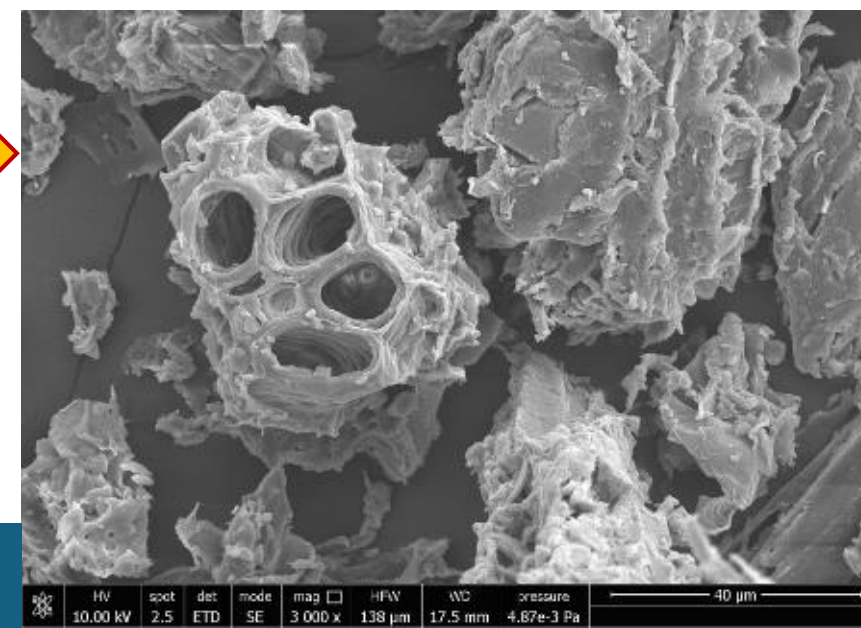
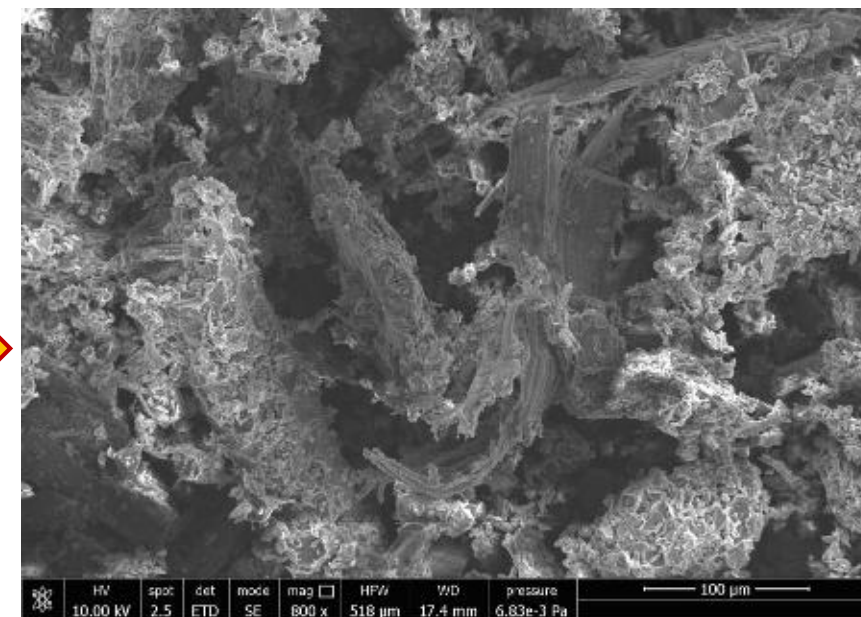
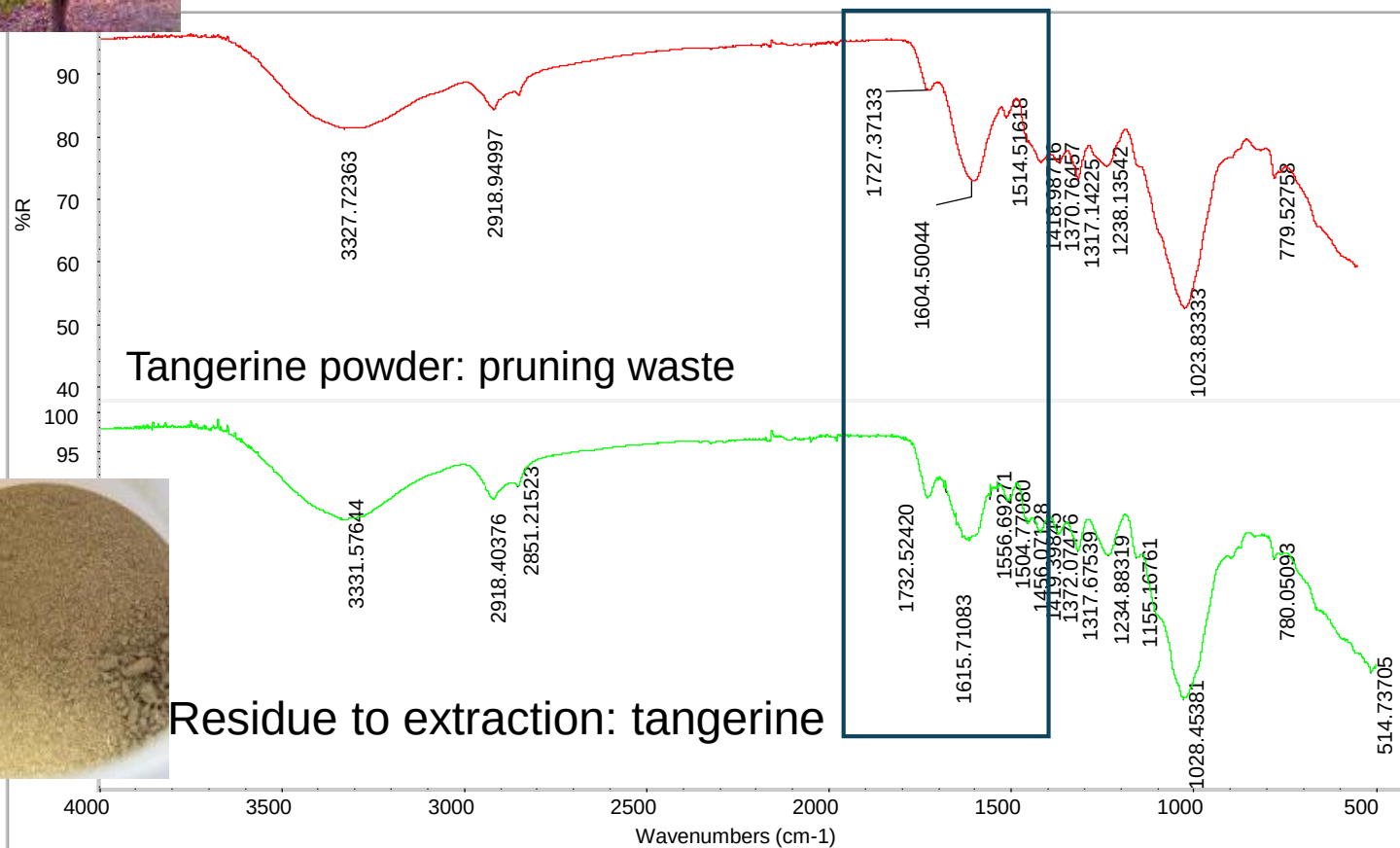
Hesperidin-enriched extracts for active food packaging from tangerine agro-industrial by-products using subcritical water extraction and resin purification

Christian Cravotto^{a,*}, Sunny Uchechukwu^a, Abdouramane Dosso^a, Doha Quebouch^{b,c}, Anouar Mouhoub^b, Florent Allais^a, Aouatif Aboudia^c, Amine Guendouz^b, Maria-Beatrice Coltelli^{d,e}, Morad Chadni^{a,*}

Fillers deriving from tangerine tree (Morocco)

Decreased and shifted peaks related to polyphenols

Spectrochimica Acta P. A: Mol. Biomol. Spectr.,153,2016,
94-101, <https://doi.org/10.1016/j.saa.2015.08.020>



After the extraction the removal of polyphenols and the formation of surfacial cavities was revealed

Step 1

Production of formulations in pellets (twin screw extrusion)



Step 2



Materials for making
citrus fruit **nets**

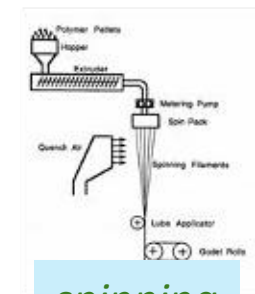
Materials for making
strawberry and date **trays**

Materials for making
films to cover trays

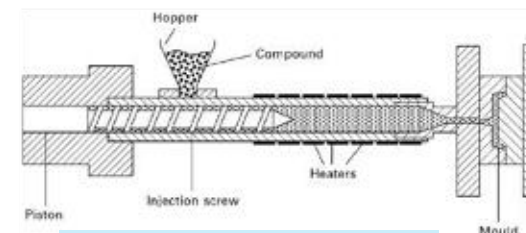
Industrial processing



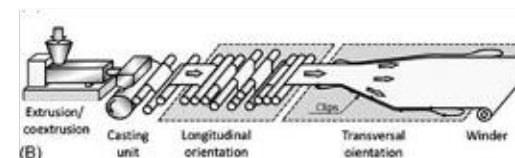
Packaging
prototypes



spinning



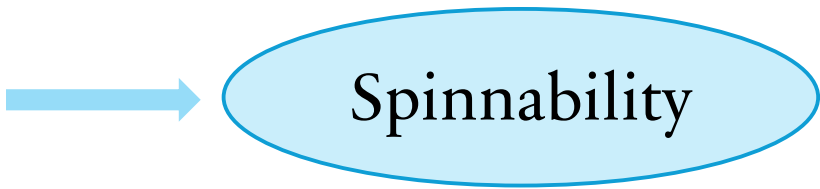
Injection molding



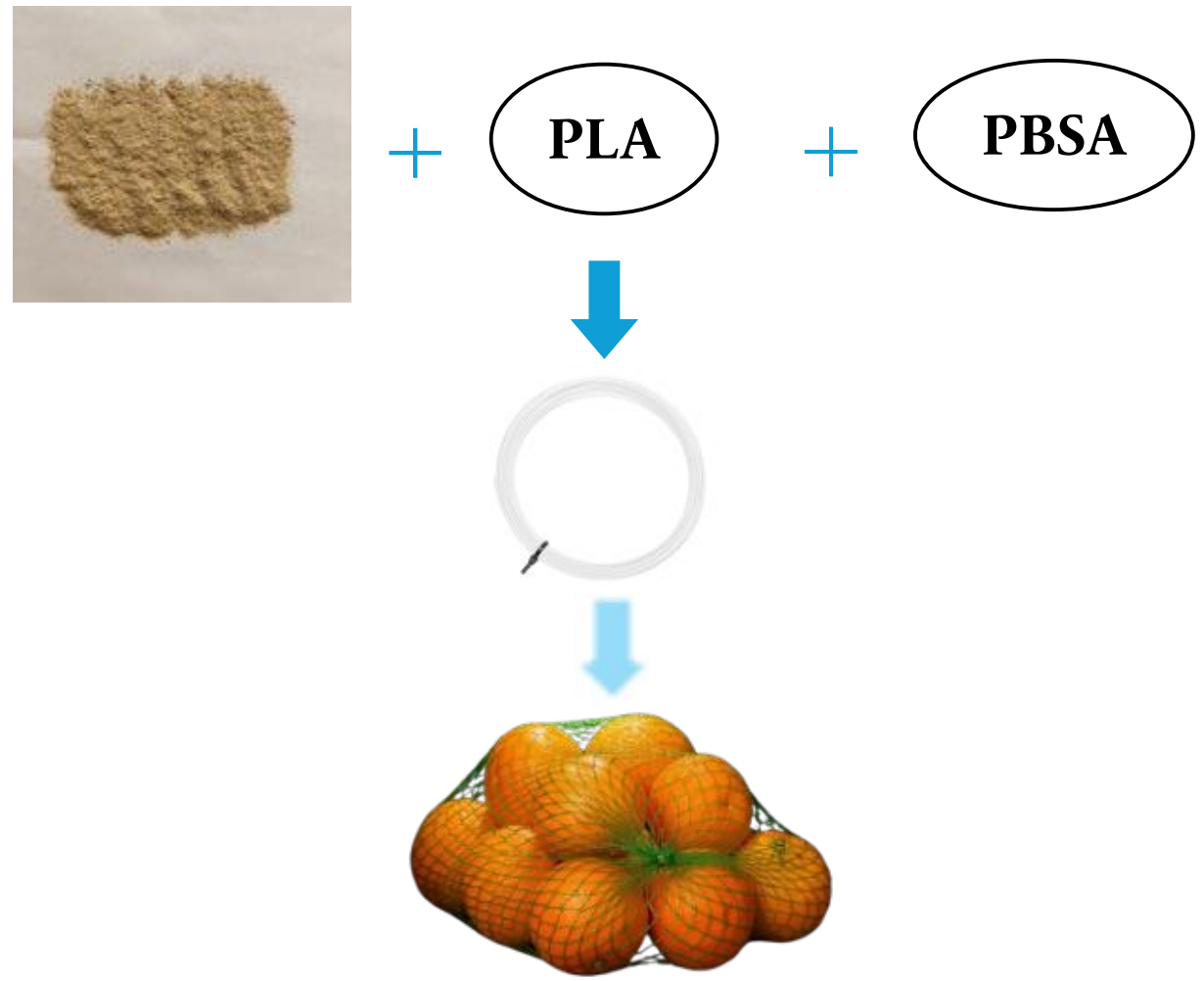
Flat die extrusion



Materials for nets



Compositions of tested materials for nets
PLA
PLA/PBSA 90/10
PLA/PBSA 80/20
PLA/PBSA 80/20 + 10 wt.% Tangerine residue PRE-extraction
PLA/PBSA 80/20 + 10 wt.% Tangerine residue POST-extraction



Materials for nets

Filaments produced by extrusion process



Parameter	SP	RPM	AMP	AMP
Value	150 °C	150	71.0%	20.8 A
Set Point	6.00 kg/h			

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11
Temperature [°C]	140	165	180	185	185	190	185	185	185	175	175



PLA/PBSA 90/10



PLA/PBSA 80/20

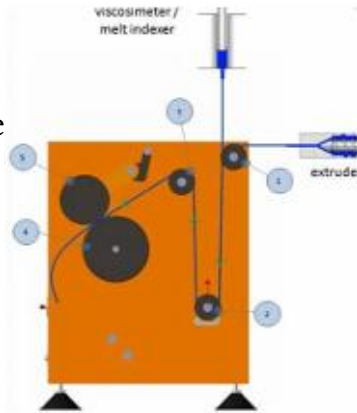


PLA/PBSA 80/20 +
10 wt.% Tangerine
residue PRE-extraction

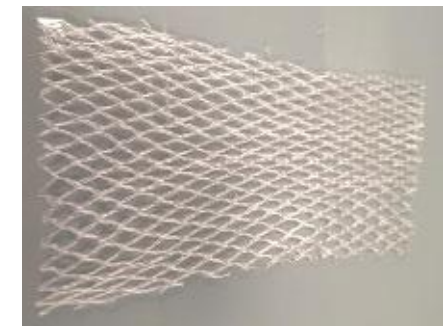
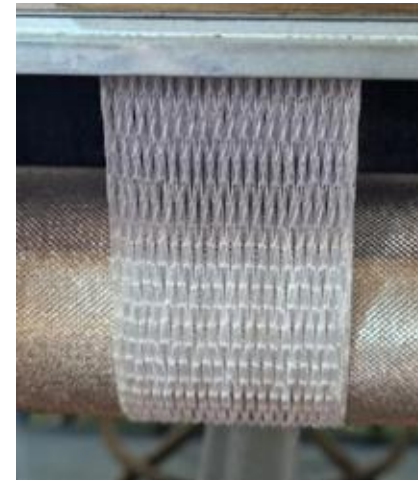
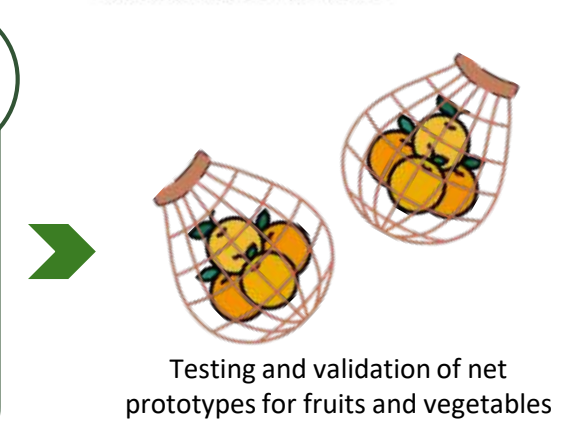
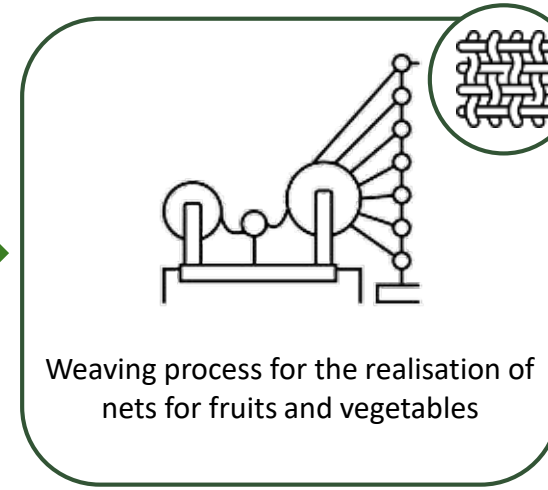
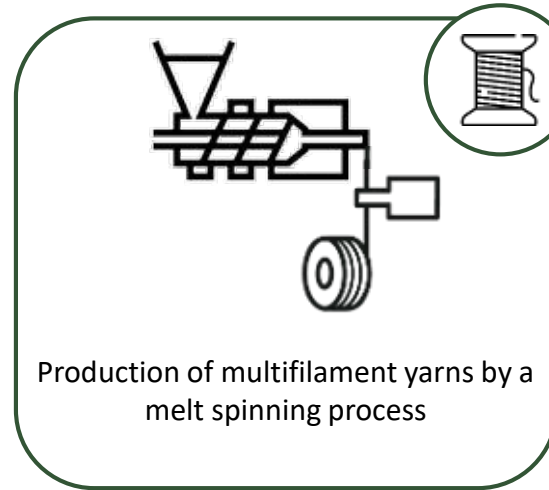
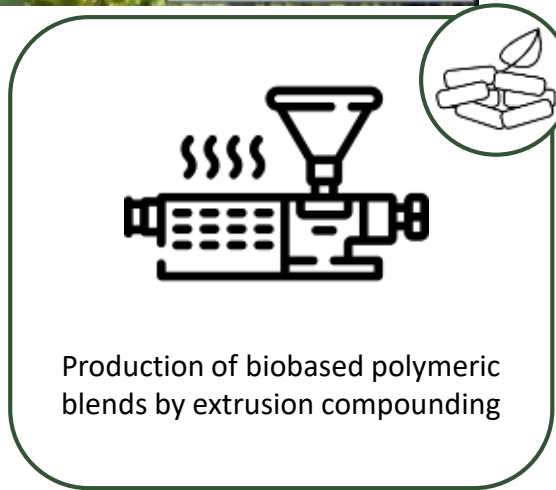


PLA/PBSA 80/20 +
10 wt.% Tangerine
residue POST-extraction

Parameter	Value
Initial speed	50 rpm
Final speed	2000 rpm
Acceleration ramp	30 rpm/s
Extrusion head output speed	150 rpm



Prototyping nets



Coating developed by UNIPI: HI Chitosan & Tangerine tree extract

Materials for trays

Rigidity
Good biodegradability
Low-cost

PLA

+



+

PBSA



Tangerine
Antioxidants

Open Access Article

Assessing PLA/PBSA Films for Sustainable Packaging for Moist and Perishable Foods

by Maria-Beatrice Coltelli * , Francesca Cartoni , Luca Panariello , Laura Aliotta , Vito Gigante *  and Andrea Lazzeri 

Department of Civil and Industrial Engineering, University of Pisa, 56122 Pisa, Italy

* Authors to whom correspondence should be addressed.

Compositions of tested materials for trays

PLA/PBSA 60/40

PLA/PBSA 30/70

PLA/PBSA 60/40 + 30% Tangerine residue PRE- extraction

PLA/PBSA 60/40 + 30% Tangerine residue POST- extraction

PLA/PBSA 30/70 + 30% Tangerine residue PRE- extraction

PLA/PBSA 30/70 + 30% Tangerine residue POST- extraction

PLA/PBSA 60/40 + 30% Tangerine residue POST- extraction +
Tangerine Antioxidants

PLA/PBSA 30/70 + 30% Tangerine residue POST- extraction +
Tangerine Antioxidants

Materials for trays



1. Granules for matrices made with **extruder**



2. **Compounding** of matrices with fillers using Minilab (laboratory-scale twin-screw mixer-extruder)

Parameter	Value
Temperature	185 °C
Screw speed	110 rpm
Material recirculation time in chamber	1 min

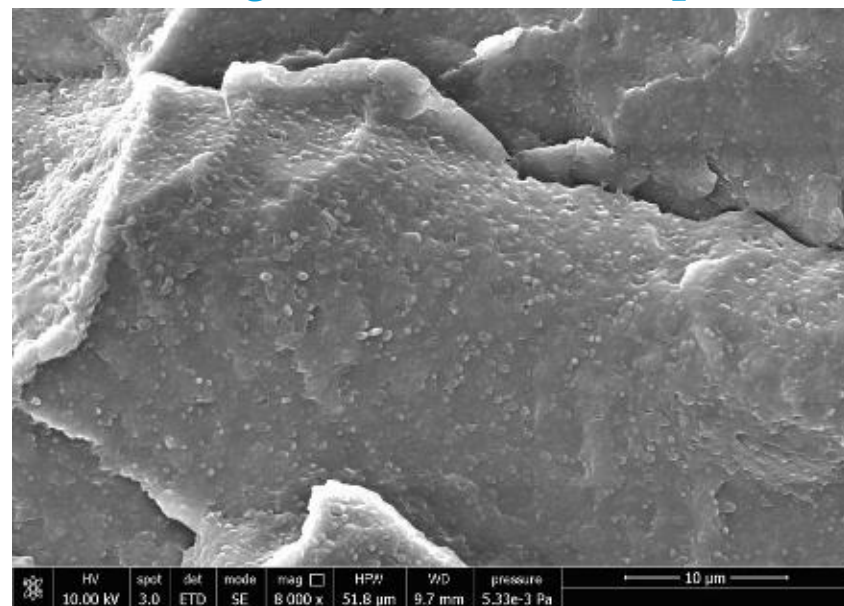


3. The HAAKE MiniJet II **piston injection molding system** was used to produce dog bone shaped samples for the characterization of tray mixes.

Parameter	Formulation 60/40	Formulation 30/70
Temperature	185°C	185°C
Injection Pressure	300 bar (7 s)	250 bar (7 s)
Counter Pressure	200 bar (3 s)	150 bar (3 s)
Mold Temperature	60°C (near PLA Tg)	50°C (near PBSA Tg)

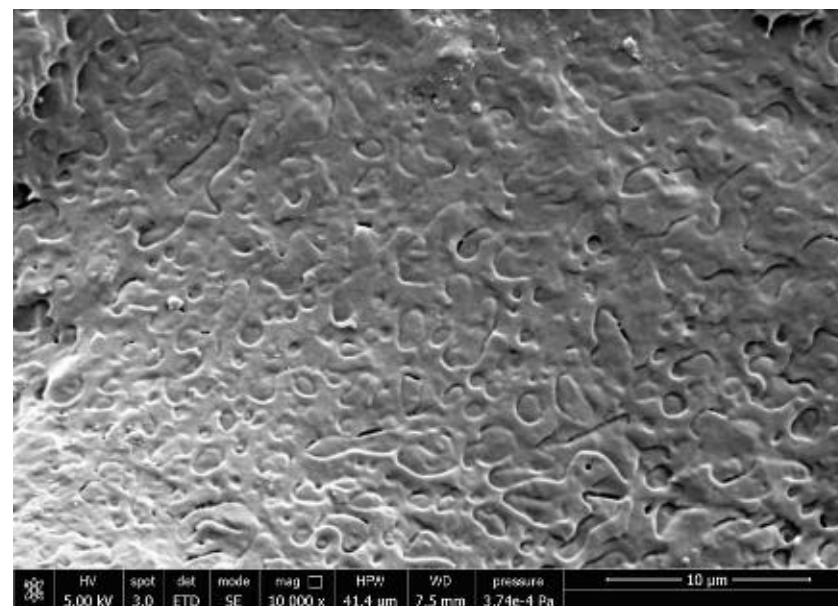


Scanning Electron Microscope



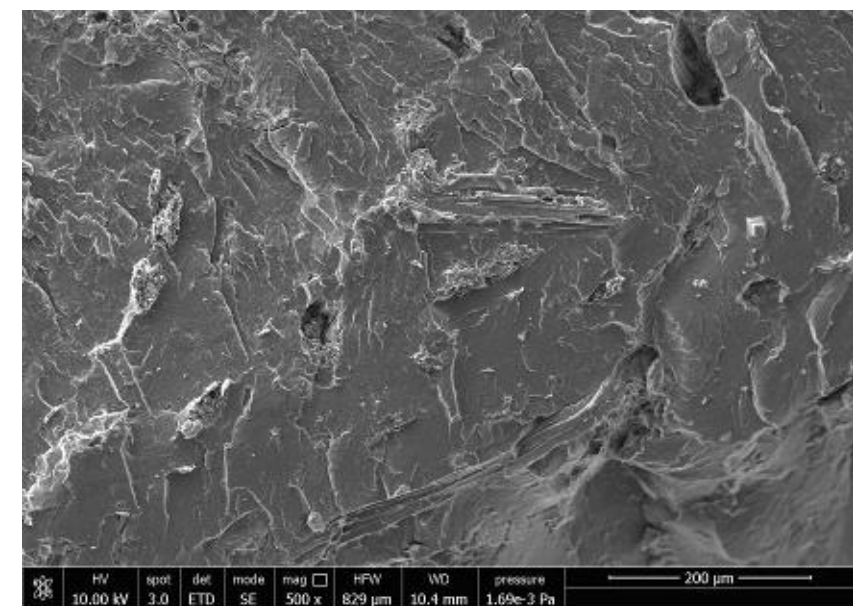
PLA/PBSA 30/70

Dispersed
blend



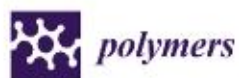
PLA/PBSA 60/40

Co-continuous
blend



PLA/PBSA 30/70 + 30%PRE

Good adhesion
between residues and
matrix is confirmed



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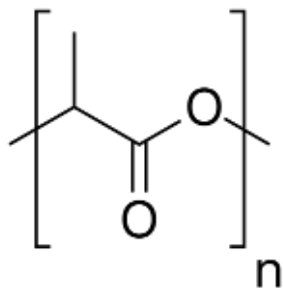
PLA/PBSA Biocomposites Reinforced with Tangerine Tree-Derived Agro-Industrial Waste for Rigid Packaging: Effect of Extraction Treatment on Morphology and Thermo-Mechanical Performance

by Francesca Cartoni¹, Viola Berrugi¹, Aouatf Aboudia², Morad Chadni³, Vito Gigante^{1,4} and Maria-Beatrice Coltelli^{1,4,*}

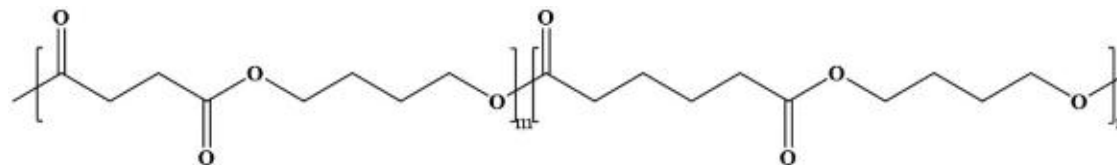
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Prototyping trays

Poly(Lactic Acid) - PLA



Poly(butylene Succinate-co-Adipate) - PBSA



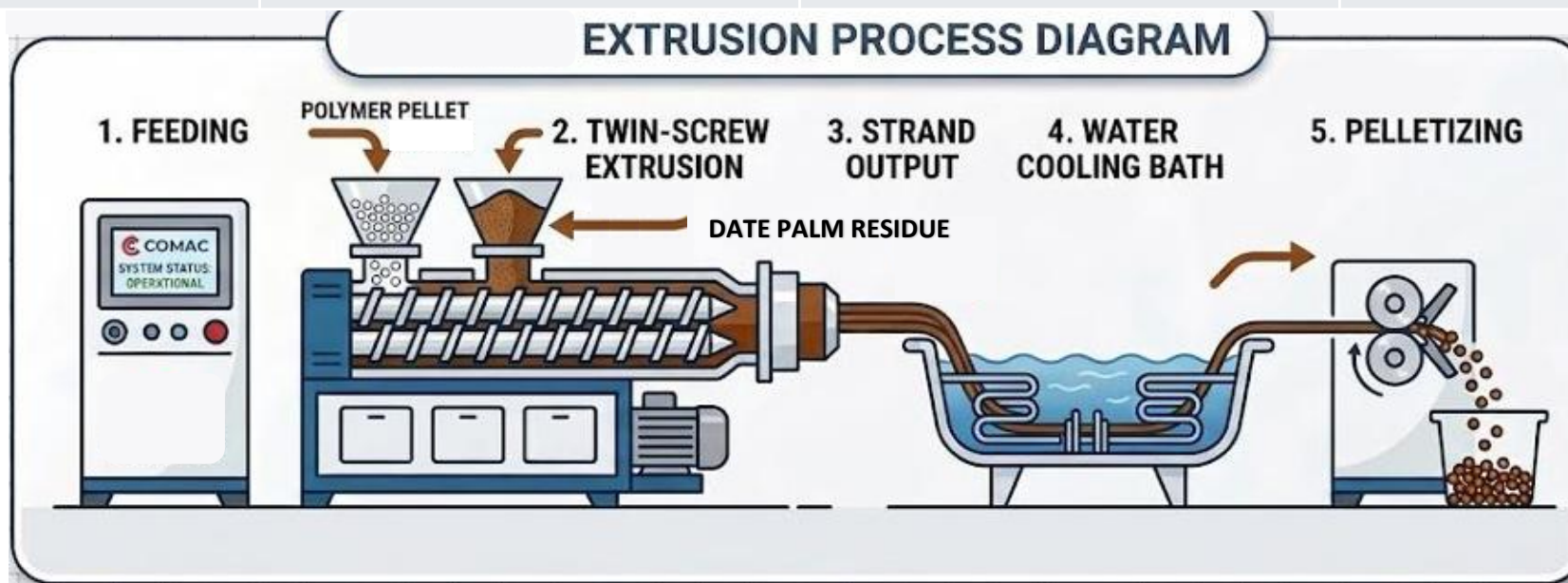
Date Palm Residues - DPR



PLAMINPACK PROJECT

Formulations & Extrusion Process

Sample Name	PLA (wt.%)	PBSA (wt.%)	Date Palm Residues (wt. %)
60/40	60	40	0
60/40 + 10DPR	54	36	10
60/40 + 20DPR	48	32	20
60/40 + 30DPR	42	28	30



Temperature Profile (°C)

Process Parameters

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11
95	150	180	185	185	190	185	185	185	175	175

Screws speed (rpm)	Feed rate (kg/h)
200	10

Injection Molding Process

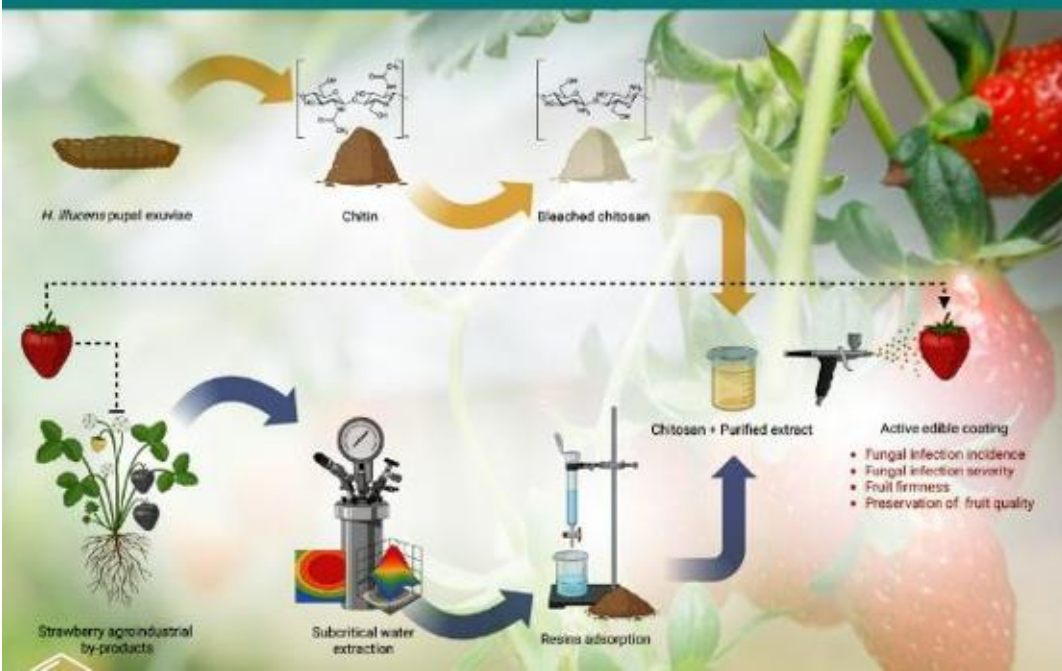


Temperature profile (°C)	190 – 195 - 200 - 200
Mould temperature (°C)	25
Injection holding time (s)	5
Cooling time (s)	5
Injection/maintaining pressures (bar)	120/90

Bioactives from Strawberry Plant Waste and Chitosan for Fruit Preservation

Polysaccharides **2026**, 7(1), 25

Volume 7 • Issue 1 March 2026



- Subcritical water extraction (SWE) maximised phenolic content and antioxidant capacity while minimising sugars' co-extraction
- (120 °C, 5 min, and S/L ratio 40) yielded a total phenolic content (TPC) of 146.9 mg GAE/g DM and an antioxidant activity of 24.8 mg TE/g DM, comparable to ethanolic reflux extraction (138.4 mg GAE/g DM and 23.4 mg TE/g DM).
- Scale-up in a Parr pressurised reactor achieved 91.2% polyphenol recovery relative to accelerated solvent extraction (ASE).
- Purification using Amberlite® XAD 7 resin enhanced TPC purity and antioxidant activity more than 2.5-fold, producing a desorbed fraction with a polyphenol purity of 93.9% (w/w, dry basis) and no detectable sugars.

Materials for films



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Viscosity,
mechanical
resistance and
flexibility suitable
for production of
cast extrusion
films

PLA + PBSA +



Strawberry
Antioxidants

Compositions of tested materials for films

PLA/PBSA 60/40

PLA/PBSA 30/70

PLA/PBSA 60/40 + Strawberry Antioxidants

PLA/PBSA 30/70 + Strawberry Antioxidants

1. Granules for matrices made
with **extruder**



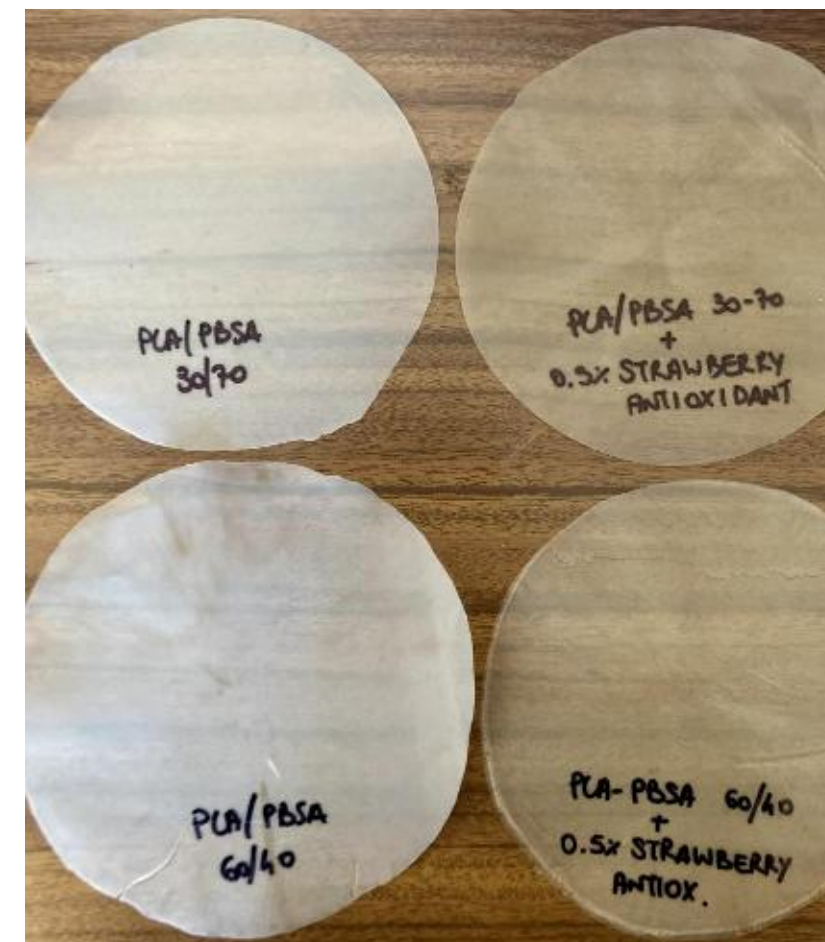
2. Compounding of matrices with
antioxidants using Minilab
(**laboratory-scale twin-screw mixer-
extruder**)

Parameter	Value
Temperature	185 °C
Screw speed	110 rpm
Material recirculation time in chamber	1 min

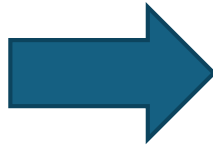


3. Film production with a
laboratory hot plate press

Parameter	Value
Material quantity	3 g
Temperature	180 °C
Pressure	2 tons
Residence time	1 min



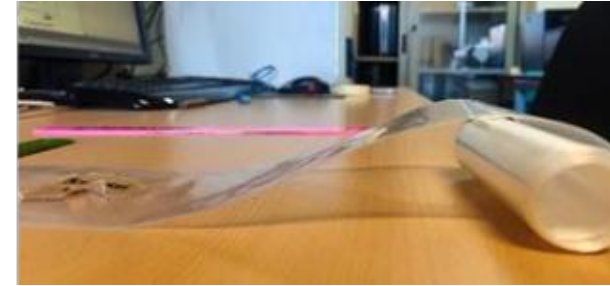
Prototyping films



The PLA/PBSA 60/40 blend resulted processable by this technique



- 120 mm of width
- About 50-100um of thickness



- The addition of anti-oxidant during extrusion was recently carried out
- A coating based on HI chitosan and anti-oxidants with good adhesiveness to films was developed

Conclusions

- PLAMINPACK project is developing easy to up-scale biobased packaging materials and methodologies (to produce nets, films, trays, coatings) reducing the loss of food, especially the most perishable ones.
- This new packaging concept will be fully inserted in the circular management of a **farm**, including specific digital tools, so that all the biomass waste is reused and contribute to generate again food, packaging, feed or amendments. Moreover, the new packaging materials will be tested for their stability under environmental conditions exposure as well as potential recyclability and environmental impacts after waste materials disposal.
- Thus, this new packaging will contribute to the growth of local businesses and job creation so that all actors along the value chains can gain from biomass valorisation.

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Registration



News



Register to PLAMINPACK results and updates

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Research true value lies not only in the knowledge we create, but also in the people we meet, the cultures we discover, and the connections that make science a truly global endeavor.

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Thank you for your attention