Exploring the valorisation potential of Tomato cultivation by-products under the frame of Circular Economy

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https://www.chemeng.ntua.gr/the_design_and_process_analysis_lab/_en

https://www.youtube.com/watch?v=lD44iDY9YRs

Laboratory of Process Analysis and Design (LPAD) is the oldest laboratory of the School of Chemical Engineering at NTUA, which has systematically contributed in the development of the School, since 1908. The area of expertise of LPAD can be summarized in (a) development of novel, functional food products, including product design, quality and sensory control of the final product, as well as shelf-life determination, (b) toolbox development for functional foods and novel processes - development of user-friendly database systems including literature data on food properties, (c) analysis of data, (d) development of mathematical models describing the physical processes and thermo-physical properties of materials, (e) experimental and applied study of the physical industrial processes, such as drying methods, extraction methods, novel encapsulation methods, etc. applied in the food industry, (f) process scale-up, (g) valorization of food waste and by-products, (h) recovery of functional compounds from various natural sources, such as plants, herbs, algae, etc. (i) in vitro digestion studies, and (k) life cycle assessment and environmental management for the determination of the economic and environmental impact of several products and processes.

LPAD personnel consists of 2 Professors, 3 permanent researchers, 4 post-doctoral researchers, 6 PhD candidates, as well as 10 undergraduate students preparing their Diploma research thesis.

Introduction

- Agricultural sector → main source of national income for most developing countries
- Agricultural industry's residues and wastes: significant proportion of worldwide agricultural productivity.
- Recover, evaluation & better valorization for all their by-products: peels, seeds, stems, and leaves.
- Creation of innovative materials for various applications.

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Introduction

Tomato:

- ✓ 3rd most important vegetable in the world
- ✓ Huge amounts of by-products: leaves, stems, ripen crops and tomato fruits rich in phenols and flavonoids, with great antioxidant, antimicrobial and antiviral activities
- ✓ No appropriate specifications for further commercialization, considered as environmental and economic problem without benefit

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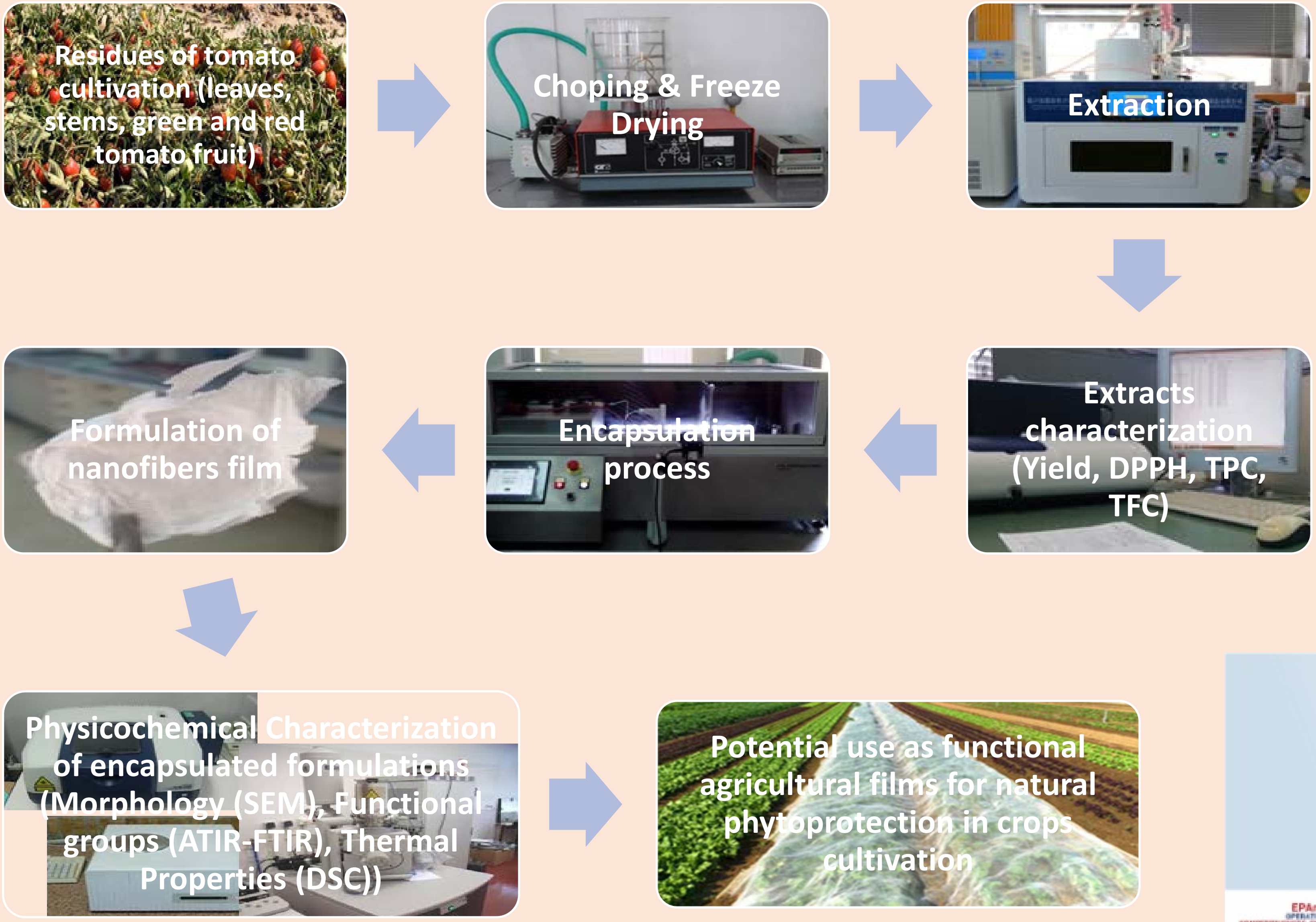
Applied processes



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Extraction processes

Ultrasound and/or Microwave assisted extraction(UAE/MAE) technology:

Innovative, quick and easy to handle at room temperature.

Extraction Method	Details
UAE 20 min	Direct extraction of the freeze- dried samples with ultrasound
UAE-MAE 20 min	Direct extraction of the freeze- dried samples with ultrasound-microwave assisted extraction
4 h-UAE 20 min	Magnetic stirring in a mixture of Ethanol: Acetic acid (95: 5 v/v) for 4 h, vacuum filtration and finally extraction with ultrasound
72 h-UAE 20 min	Magnetic stirring in a mixture of Ethanol: Acetic acid (95: 5 v/v) for 72 h, vacuum filtration and finally extraction with ultrasound

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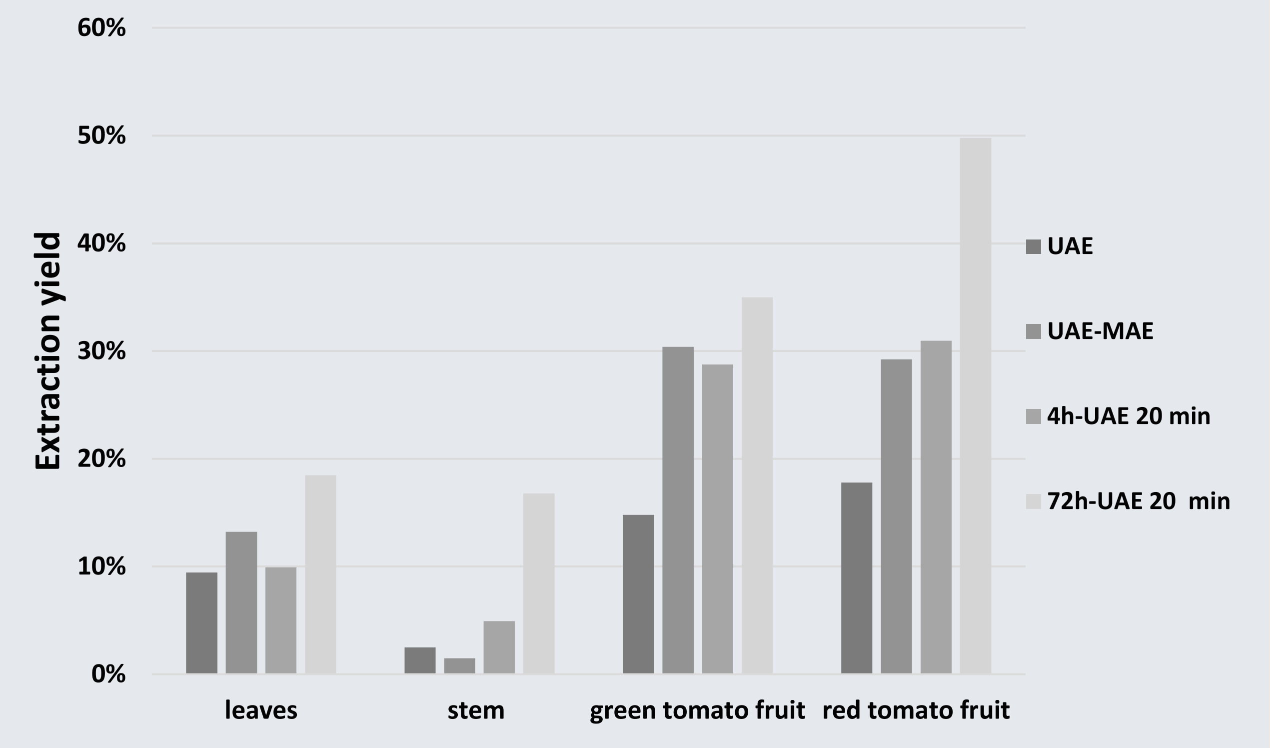
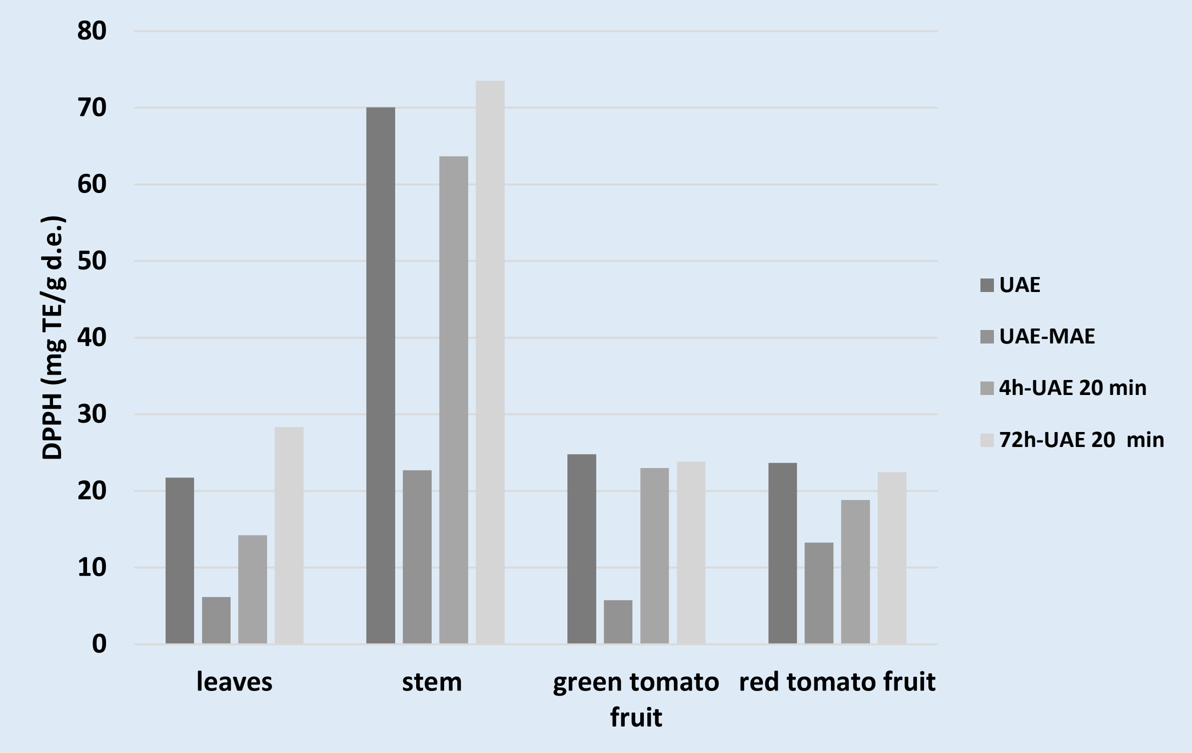
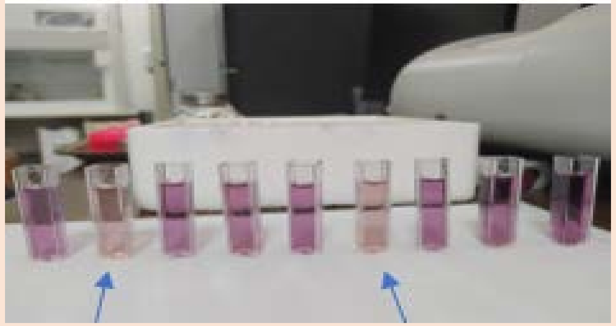
Extracts Characterization- Extraction Yield

- Red and green tomato fruit showed high extraction yields
- 72 h maceration favors extraction yielding
- Extraction of dry sample with UAE gives the lowest yield
- In red and green tomato fruit the effect of US and MW combination is equal to the 4h maceration.



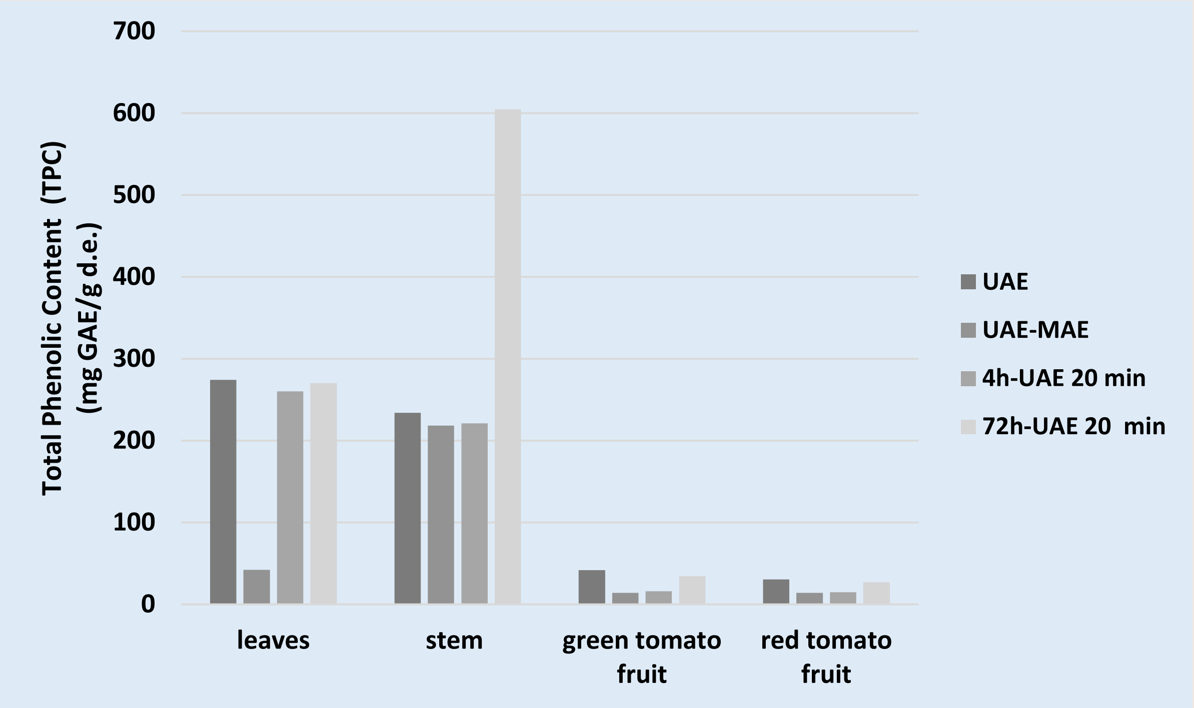
Antioxidant activity (DPPH)





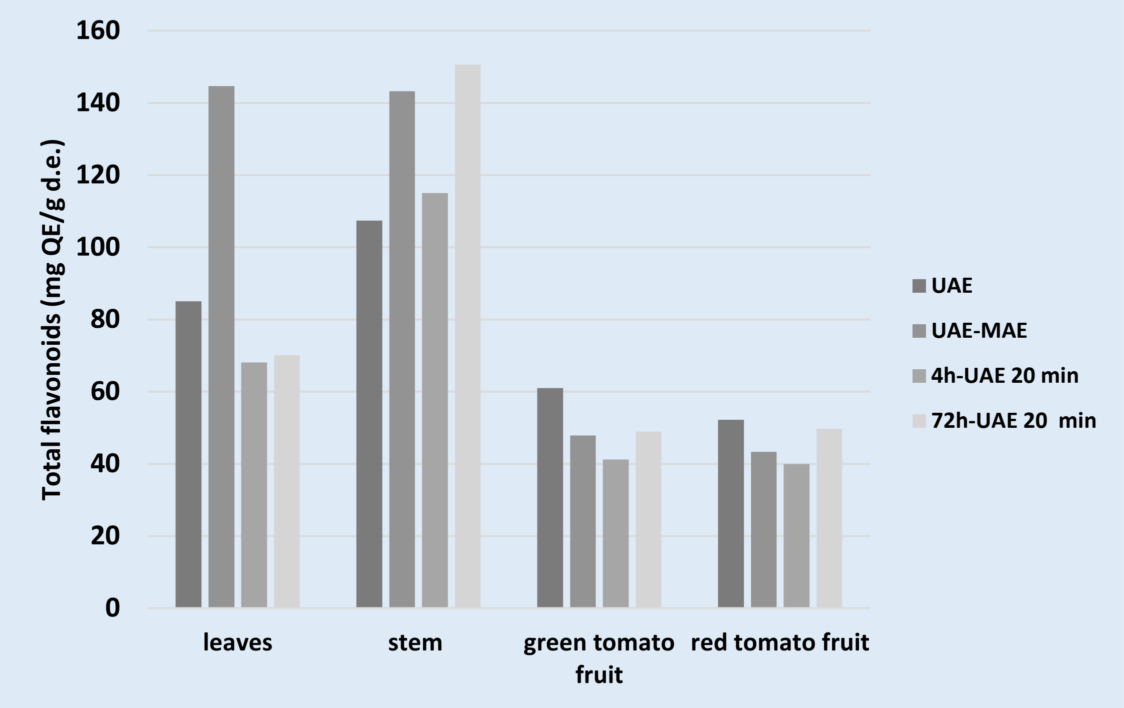
- The combination of US and MW significantly affects the antioxidant activity – Tensive heating degrades antioxidant compounds
- The maceration pre-treatment slightly affects the antioxidant activity- A positive impact is detected in plant parts with lignocellulosic fibers.

Total Phenolic Content (TPC)



- All the extracts derived from tomato fruit showed significantly low phenolic content, regardless of the extraction method used.
- Stem extract derived from 72 h maceration and UAE exhibited the highest TPC indicating the positive effect of maceration in plant materials with high lignocellulose fibers content.
- The UAE-MAE in leaves extracts degrades significant the phenolic compounds.

Total Flavonoid Content (TFC)

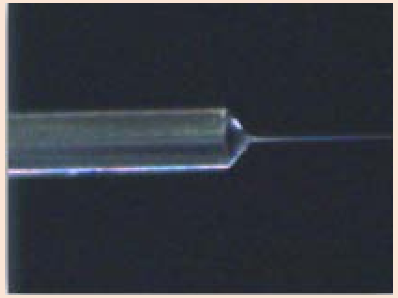


- All biomass fractions exhibited good flavonoid content.
- Stem samples exhibited the highest flavonoid content for all the extractions with 72 h maceration and UAE having the highest value followed by direct UAE-MAE.
- Leaves extract from UAE-MAE showed the second highest value among all the samples.
- Finally, all extracts of green tomato fruit showed similar flavonoid content with the red and lower than the other parts.

Encapsulation process

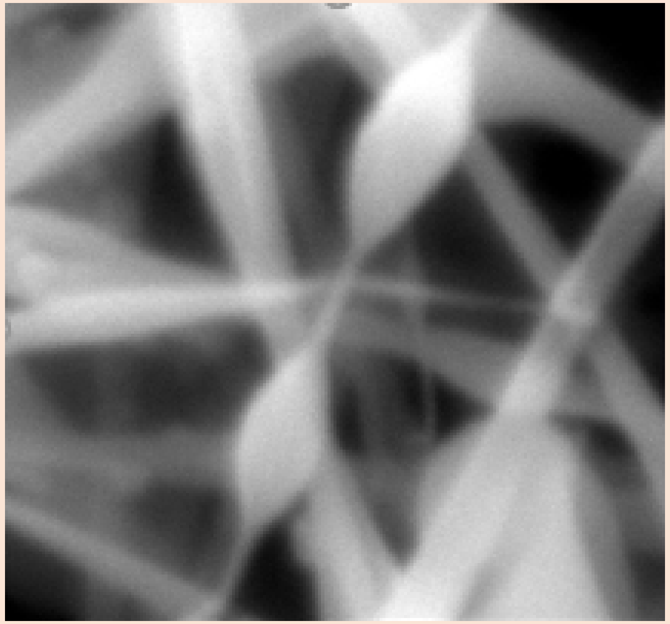
Wall material	Tip-collector distance (cm)	Flow (mL/h)	Applied Voltage (kV)	Comments
ZN	3	0.3	18.5-20	Very close - low flow rate- Nozzle blockage due to immediate drying of material at the outlet - unstable Taylor cone
	5	0.4	18.5-23	
	7	0.5	21-23	
	9	0.7	23-25	Better distance & flow- Droplets in the collector / unstable Taylor cone
	11	0.6	23-25	
	13	0.8	24-26	Better distance & flow but equally unstable cone and spray with previous case
	13	0.9	24-26	
	15	**1**	**25-27**	**Satisfactory distance & flow- Stable Taylor cone**
PLA	3	0.6	17-18	Very close- unstable Taylor cone- indication of improvement with the gradual increase of the three parameters
	5	0.8	18.5-20	
	7	1	21-23	
	9	1.3	23-25	Better distance & flow but unstable Taylor cone
	11	1.5	23-25	
	13	1.7	25-27	
	15	**2**	**26-27**	**Satisfactory distance & flow- Stable Taylor cone**

Electrohydrodynamic process

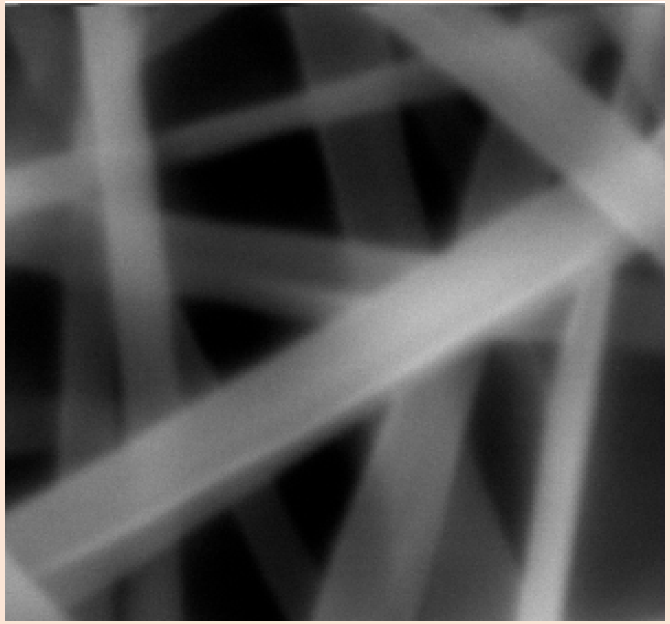


Electrospun fibers characterization-SEM

ZN matrix



PLA matrix



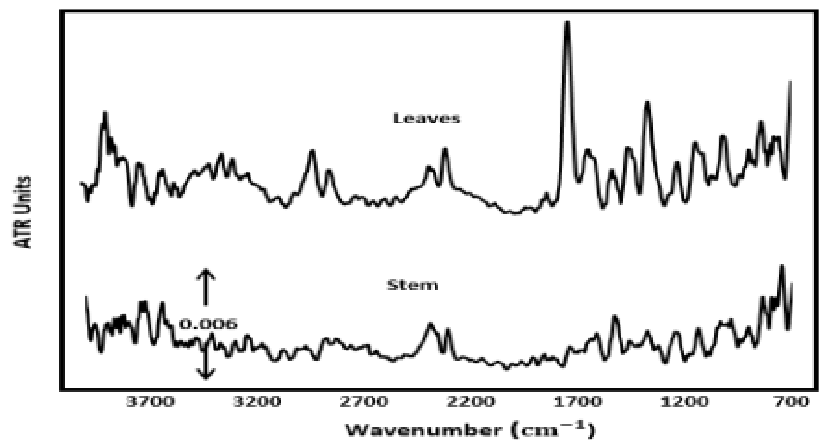
✓Fiber formation through the electrospinning apparatus.

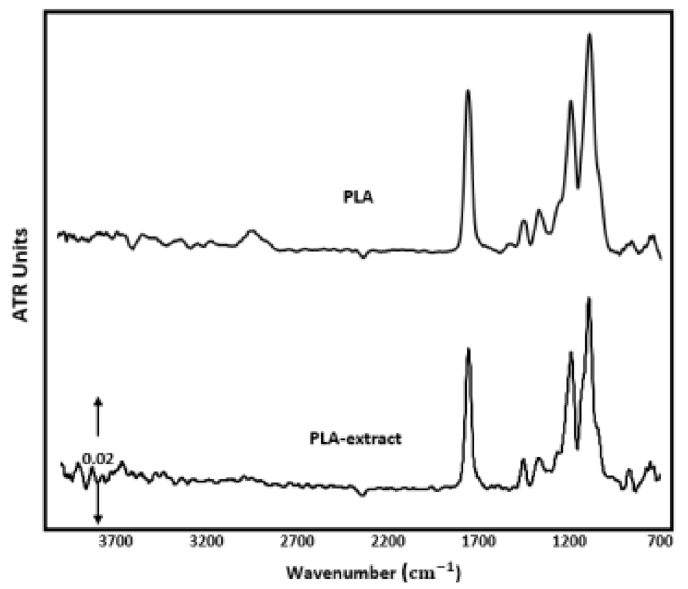
✓ Inclusion of the extract inside the polymeric matrix at several points of the fibers.

✓ The average diameter of the generated fibers was calculated at 391 ± 83 nm (ZN matrix) and 572 ± 79 nm (PLA matrix).

Attenuated Total Reflectance (ATR-FTIR)

Determination of the functional groups of each material- Examination of their interactions in the particles produced by the encapsulation methods.





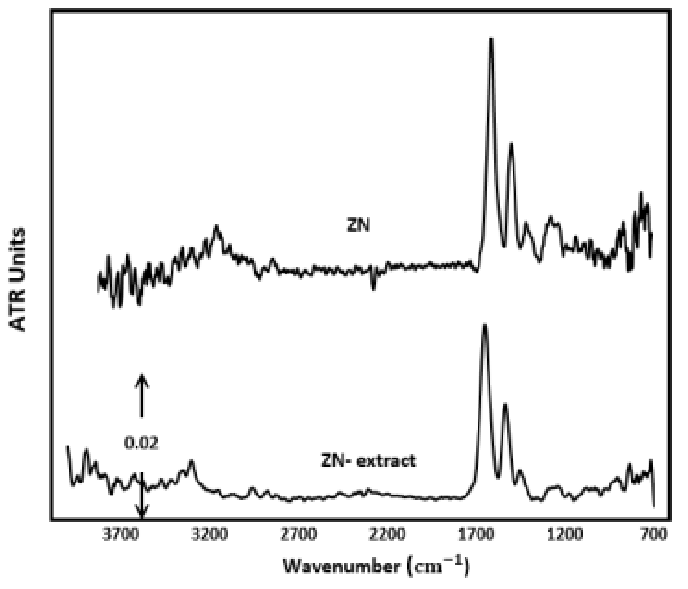
PLA:1780- 1680 cm^{-1} (C = O), 1500-1180 cm^{-1} (C = O & C – O – C bonds) a slight difference in the shape of the peak at 1780-1680 cm^{-1} (sharper peak) in the case of the encapsulation product indicates the presence of the extract.

No alterations or disappearance in the characteristic peaks of the polymers- naturally/physically encapsulated compounds- no chemical bonds created that would change the properties of the compounds or the wall material.

ZN: 1652-1705 cm^{-1} (Amides I - C = O bond & info on the secondary structure of the protein- symmetrical peaks - highest amount of α-helices in the secondary structure)

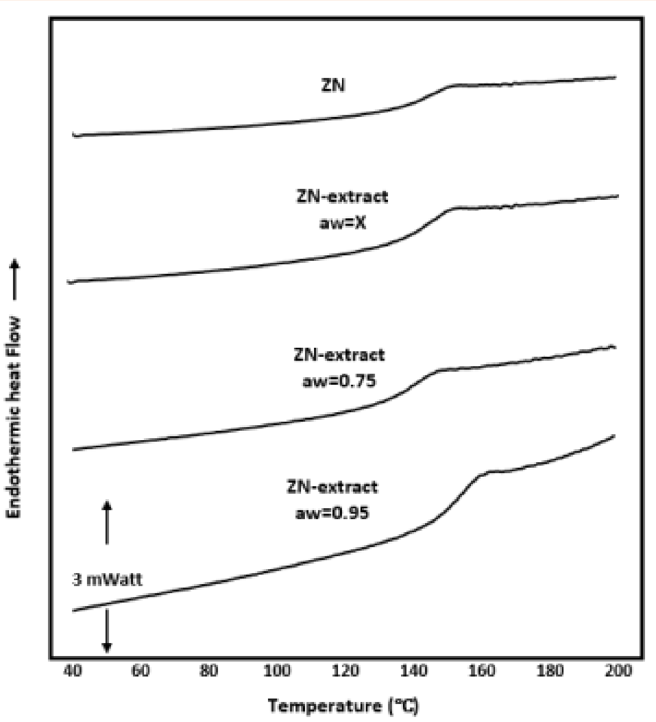
1531 cm^{-1} (Amide II (bending vibration of N-H and C-N).

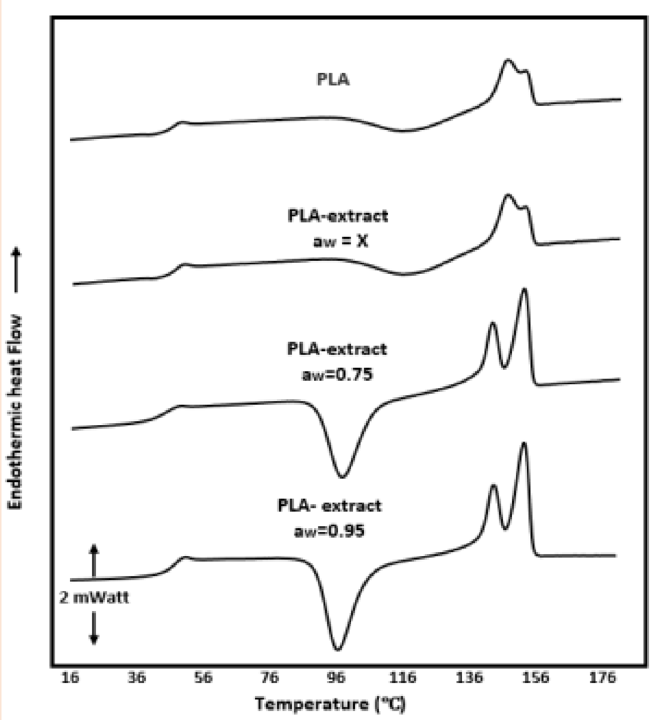
Slight shift of the Amides' peaks to smaller wavenumbers and a small widening- indication of encapsulation given that especially the leaves show a peak at 1700 cm^{-1} which probably contributes to this differentiation from the pure matrix (without encapsulated compound).



Differential Scanning Calorimetry (DSC)

2nd heating cycle





Thermal behavior of the electrospun fiber in ZN and PLA after previous stay in different humidity chambers (aw=0.75 and 0.95) compared to completely dry sample

Sample	Tg (°C)
Pure ZN	145.16
ZN-Extract (dry)	143.29
ZN-Extract (a_w=0.75)	141.51
ZN-Extract (a_w=0.95)	141.27
Pure PLA	47.80
PLA-Extract (dry)	47.86
PLA-Extract (a_w=0.75)	47.23
PLA-Extract (a_w=0.95)	47.31

ZN: Tg between 141-143 °C for all samples- no effect from moisture (2 degrees lower than Tg of pure ZN- indication of successful encapsulation).

PLA: Tg at 47-48 °C for all samples- Crystallization at 97 ℃ only for the samples derived from high relative humidity environment. Effect of moisture -Crystallization results in increased fragility and reduced stress resistance.

Discussion

- The effective valorization of stem, leaves, green and red tomato fruit can turn these by-products into a cheap source of natural antioxidant and antimicrobial compounds.
- Stems and leaves exhibited the higher bioactive content compared to the tomato fruit extracts.
- The pretreatment for 72 h with the extraction solvent and UAE was the most effective technique since it led to the highest quality extracts.
- Successful production of electrospun films with encapsulated tomato waste extracts.

Potential Uses

- Strong shift to organic farming in recent years → no use of chemical pesticides and fertilizers
- Valorization of the antimicrobial, antioxidant and anti-pesticide activities of the tomato waste extracts
- Creation of advanced soil cover films in crops cultivation for ecofriendly plant protection based on the great properties of the tomato waste bioactive compounds

Thank you for your attention!

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