UNRAVELLING THE POTENTIAL OF MEDITERRANEAN CITRUS BY-PRODUCTS: M.E.D.I.S.M.A.R.T. PROJECT OVERVIEW

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Introduction

Citrus fruits, widely abundant and distributed worldwide, give rise to substantial by-product quantities, potentially reaching up to 120 million tons each year, being the Mediterranean region a key producer in this context. Specifically, within this geographical area, Portugal's citrus fruits cultivated under the Protected Geographical Indication (PGI) designation constitute a significant agricultural sector, which resulted in a production of approximately 398.83 thousand tons, in 2019 [1]. Nevertheless, the processing of these fruits results in significant waste materials such as seeds, peels, and pulp, which make up 45% to 50% of the fruit and contribute to environmental issues such as water and land pollution [2, 3]. This challenge is further exacerbated by the increasing global population, which exerts mounting pressure on our food systems. However, citrus by-products hold great promise as a source of bioactive ingredients, offering solutions to maximize food utilization, promote upcycling, and introduce innovative nutritional and health benefits [3]. This potential is especially evident in citrus peels, which are rich in valuable compounds like essential oils, fiber, and polyphenols.

Objectives

Under the frame of the M.E.D.I.S.M.A.R.T. Project (Partners: UCP, NRC, SSICA, AMC, CRIFFC and Tarimaș) was aimed the development of a sustainable and integrative approach based on green chemistry principles to valorize different Mediterranean citrus by-products (orange; lemon, mandarin and grapefruit peels) in a way to promote circular economy within the industry.

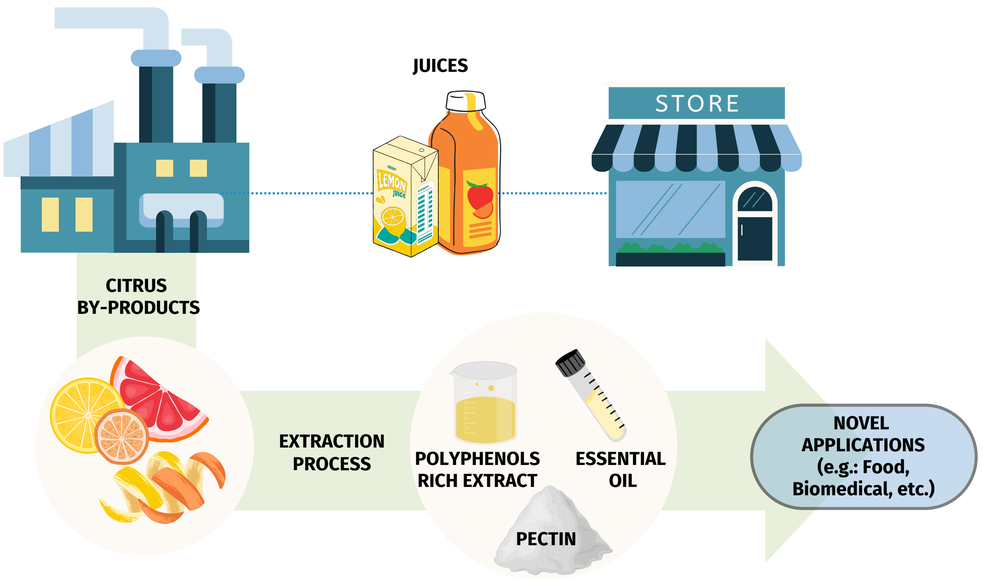
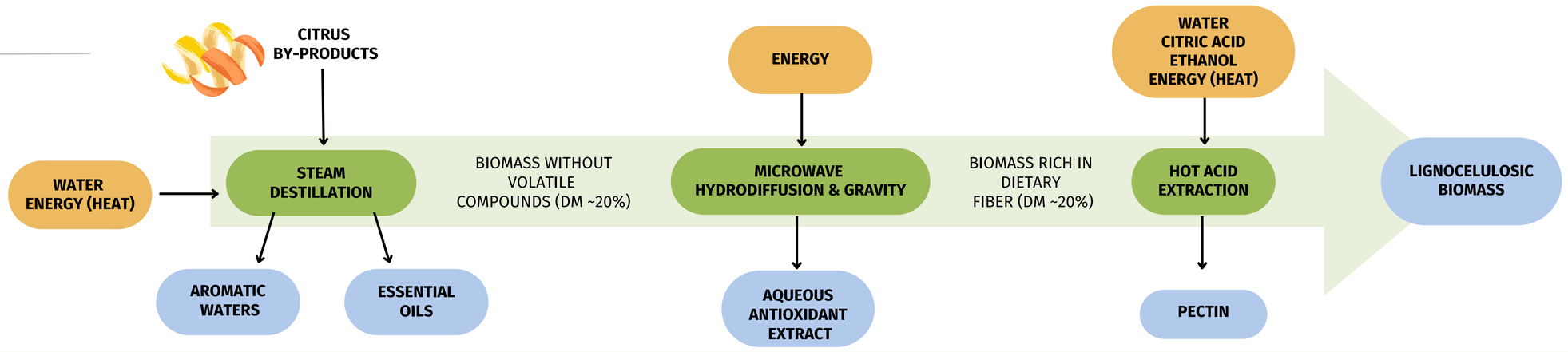


Figure 1. Citrus by-products obtention process and upcycling diagram.

Methods



MAJOR BIOACTIVE COMPOUNDS	OXYGEN-CONTAINING COMPOUNDS	LIMONENE	HESPERIDIN NARIRUTIN	D-GLACTURONIC ACID	CELLULOSE LIGNIN
BIOACTIVITIES	ANTISÉPTIC ANTIMICROBIAL ANTI-AGING	ANTIMICROBIAL ANTIOXIDANT ANTI-INFLAMMATORY	ANTIOXIDANT ANTI-INFLAMMATORY GUT MODULATION ANTI-CANCER	PREBIOTIC ACTIVITY ANTI-OBESITY ANTI-DIABETIC	ANTIOXIDANT ANTIMICROBIAL
APPLICATIONS	AROMOTERAPY CLEANING PRODUCTS COSMETICS	NATURAL PRESERVATIVE COSMETICS GREEN PESTICIDES	NURACEUTICAL PHARMACEUTICAL INDUSTRY	FOOD INDUSTRY PHARMACEUTICAL INDUSTRY PACKAGING MATERIAL	BIOPOLYMERS BIOFUELS HYDROGELS FLAVORING AGENTS

Figure 2. Integrated biorefinery strategy for citrus by-products valorization. Adapted from *Vilas-Boas et al., 2023* [3].

Results & Main Conclusions

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Table 2. Citrus by-products bioactivities

	Polyphenols-Rich Extracts				Essential Oils			
	Orange	Lemon	Grapefruit	Mandarin	Orange	Lemon	Grapefruit	Mandarin
ABTS (IC50 mg/mL)	4.1		N/A			N/A		
*DPPH (% inhibition)**	96.7	98.6	92.3	99.0	76.2	86.4	65.8	81.3
*NOF (% inhibition)**	93.5	97.1	90.0	99.3	79.4	83.9	64.7	83.9
Anti-inflammatory ***(IC50 µg/mL) (COX1/COX2)***	12.5/ 0.1	35.0/ 0.2	25.0/ 0.3	14.5/ 0.1	40.0/ 0.6	12.5/ 0.1	N/A	24.3/ 0.3
Antihypertensive	19.8		N/A			N/A		

*at 2 g/mL for essential oils and 1g/mL for polyphenols extracts.

Table 1. Citrus by-products chemical composition.

Polyphenols-Rich Extracts (mg/g)	Essential Oils % (w/w)
Hesperidin (3.25 – 3.60)	D-limonene (17.76 - 94.75)
Eriocitrin (18.29)	γ-terpinene (7.52 - 8.17)
Narirutin (1.62)	α-pinene (6.61 - 11.32)
Naringenin (0.08 – 1.48)	β-pinene (7.71 - 15.64)
	Myrcene (0.95 - 13.52)

Table 3. Antimicrobial properties of lemon and orange's peels essential oils.

	Lemon Oil			Orange Oil		
	MIC (mg/mL)	MBC/MFC (mg/mL)	IZD (mm)	MIC (mg/mL)	MBC/MFC (mg/mL)	IZD (mm)
S. aureus	21.5	Non	12.5	172.1	Non	10
S. enterica	86.1	459.0	13.0	Non	Non	Non
E. coli	28.7	Non	10.2	Non	Non	Non
L. monocytogenes	10.5	37.5	12.7	172.1	Non	N/A
A. niger	3.6	57.4	N/A	7.17	229.5	N/A
F. verticilloides	28.7	28.7	N/A	Non	Non	N/A
P. epansum	14.3	14.3	N/A	114.8	459.0	N/A
Clodosporiun spp.	0.9	3.6	N/A	0.9	14.3	N/A

ATR-FTIR PROFILE OF CITRUS PEELS' PECTIN

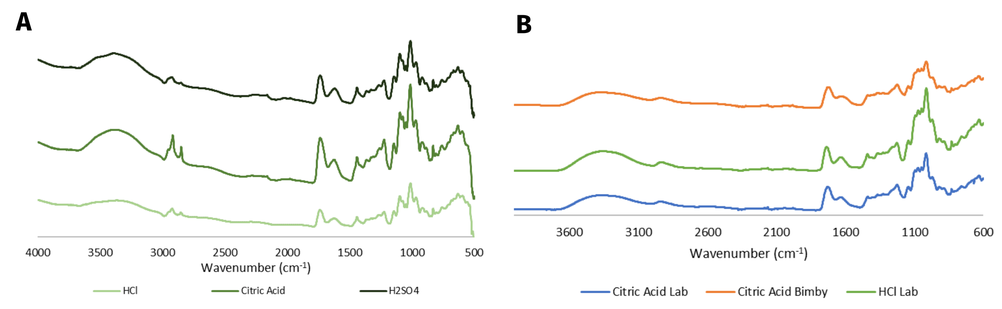

Figure 3. FT-IR spectra of the pectin extracted from fresh lemon's (A) and orange's (B) peel according to different extraction variables. HCl - Pectin extracted using acid chloride-acidified water; Citric Acid – Pectin extracted using citric acid-acidified water; H2SO4 – Pectin extracted using sulfuric acid-acidified water.

Table 5. Nutricional and chemical profile of citrus pectin according to different extraction variables.

Sample	Method	Acid	Yield (%)	Protein (%)	Moisture (%)	Ashes (%)	DE (%)
Lemon	Conventional	Citric	32.9	5.2	10.0	2.1	70.1
		HCl	33.5	4.7	8.5	1.8	88.5
		H2SO4	25.6	4.7	8.8	3.1	88.0
Orange	Conventional	Citric	36.1	5.9	7.5	1.4	69.7
		HCl	28.1	5.7	6.7	1.7	85.4
	Kitchen Robot	Citric	35.4	5.5	4.9	2.7	72.1

Overall, M.E.D.I.S.M.A.R.T. has been able to develop new added-value citrus-based ingredients, aiming to achieve the zero-waste concept, following the EU recommendations for 2030 and promoting the Mediterranean economy in various sectors, namely food, nutraceutical, biomedical and cosmetic applications.

References

[1] FAO Citrus Fruit Statistical Compendium 2019.
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Acknowledgments

The authors would like to thank the MEDISMART project (reference PRIMA/0014/2019) for support and the scientific collaboration of CBQF under the FCT project UIDB/Multi/50016/2020. In addition, the authors Ana A. Vilas-Boas and Daniela Magalhães would like to acknowledge FCT for the individual Ph.D. grant (2020.05655.BD and 2022.12417.BD).

The PRIMA programme is supported and funded under Horizon 2020, the Framework European Union's Programme for Research and Innovation