Supporting Information

From batch to flow: Integrating in-line (deep) eutectic solvents with sequential downstream processing for sustainable biomass valorization

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TABLES

Table S1. Detailed scores for each principle according to the Path2Green metric, which is based on the 12 principles of green extraction. Principle 5 is evaluated in the context of both batch (orange) and semi-continuous processes (Green).

Green Extraction Principles	Attributed Weight[a]	Score	Reason
Principle 1 – Biomass: Prioritize biomass that is naturally sourced or produced with minimal resource input.	**6.00**	**+1.00**	The pomegranate utilized in this study is classified as a byproduct of the juice industry.
Principle 2 – Transport: Preservation of biomass integrity and minimization of environmental impacts associated with transport.	**5.00**	**-1.00**	Although the biomass utilized in this study was industrial waste, it was transported from California, USA, to the extraction site in Portugal. The overall assessment could be improved by implementing the biorefinery process closer to the biomass source.
Principle 3 – Pre-treatment: Optimization of pre-treatment avoidance and cost-effective techniques.	**2.50**	**-0.20**	The used biomass was subjected exclusively to physical pretreatment methods.
Principle 4 – Solvent: Solvent usage should be minimized, with preference given to solvents that are of biological origin, biodegradable, and non-toxic.	**6.00**	**0.00**	A three-step biorefinery approach was established to recover three valuable products from pomegranate waste: anthocyanins, an ellagic acid-rich fraction, and biochar material. The process employed three solvents: bio-based gamma-valerolactone (scoring 0.00 in the CHEM21 database), cholinium acetate (which can be synthesized as a bio-based ionic liquid but is primarily produced via synthetic routes, also scoring 0.00), and a eutectic solvent composed of cholinium chloride and oxalic acid. Although these solvents represent a more sustainable alternative to conventional fossil-fuel-based volatile organic solvents, concerns regarding their production persist. Therefore, a neutral score (0.00) was assigned in this metric to account for these factors.

Principle 5 – Scaling: Ensuring reproducibility and establishing a continuous extraction flow. ***Fig. 5. A. Batch process***	**5.00**	**-1.00**	A batch biorefinery process was employed, which presents challenges for scaling-up. However, the operational units utilized in this process can be replaced to enable at least semi-continuous operation.
Principle 5 – Scaling: Ensuring reproducibility and establishing a continuous extraction flow. ***Fig. 5. B. Semi-continuous process***	**5.00**	**+0.50**	A semi-continuous biorefinery approach was adopted, although some operational steps may still pose challenges for industrial scale-up.
Principle 6 – Purification: The intended final application determines the required degree of purification.	**2.50**	**+1.00**	Anthocyanin and ellagic acid-rich extracts were obtained in a ready-to-use form without requiring further purification.
Principle 7 – Yield: Optimize the utilization and valorization of biomass resources.	**4.00**	**+1.00**	The process achieves complete valorization of the biomass, resulting in no residual biomass at the conclusion.
Principle 8 – Post-treatment: Enhancing the functionality of natural products following extraction to optimize their beneficial properties.	**2.50**	**+1.00**	Ready-to-use extracts, including anthocyanins and ellagic acid-rich fractions, were obtained without the need for purification or additional post-treatment strategies.
Principle 9 – Energy: Emphasize the adoption of clean energy sources and advanced high-efficiency extraction techniques.	**5.00**	**+0.50**	An extraction technique with minimal dependency was implemented utilizing renewable energy sources.

Principle 10 – Application: Ensure safety for applications across multiple sectors.	**4.5**	**+1.00**	The extracted anthocyanins, ellagic acid, and their derivatives have potential applications across multiple sectors, including pharmaceuticals, nutraceuticals, cosmetics, nutrition, food, biomedicine, and various consumer products.
Principle 11 – Repurposing: Develop strategies for implementing closed-loop extraction systems, preferably using non-virgin materials.	**6.00**	**+1.00**	Non-virgin raw materials were used.
Principle 12 – Waste management: Enhance waste minimization and ensure effective waste management.	**6.00**	**+1.00**	A zero waste biorefinery approach was implemented, resulting in the production of biochar.

[a] *Weight selected according to preconized in Path2Green original article*