

Valorisation of snail processing waste for sustainable agriculture within a circular economy framework

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The circular economy promotes the recovery and reuse of secondary resources in order to minimise waste generation and reduce reliance on virgin materials (Barbhuiya, Das and Adak, 2024). In this context, agri-food by-products represent an important yet underexploited resource stream. Snail processing generates significant quantities of organic and mineral residues, including hepatopancreas, tissue fragments, mucus, and shells, which can be transformed into value-added products for sustainable agriculture (Laohavisuti *et al.*, 2025).

This study presents a circular economy-based approach for the valorisation of snail processing waste derived from *Helix pomatia*, focusing on the recovery of nutrient-rich liquid extracts and solid organo-mineral fractions (Gupta and Khanal, 2024). A maceration process was applied to a homogenised mixture of hepatopancreas and associated biological by-products, conducted under controlled conditions. The prolonged maceration promoted the solubilisation of organic compounds and nutrients, yielding a homogeneous brown liquid extract. Analytical results revealed a very high content of dissolved organic carbon, with non-purgeable organic carbon values of approximately 7.7 g C/L, alongside elevated total nitrogen concentrations, indicating a solution rich in proteins, peptides, amino acids, and complex organic compounds.

Chemical oxygen demand measurements revealed very low values, despite the high organic carbon content, indicating the predominance of refractory organic matter resistant to rapid oxidation. This combination suggests a stable extract with potential for slow nutrient release and reduced risk of oxygen depletion, making it suitable for long-term soil conditioning applications. The liquid fraction was separated by vacuum filtration and characterised for TOC, TN, and COD, while the retained solids were dried and processed into organo-mineral fractions with controlled granulometry.

In parallel, solid fractions derived from hepatopancreas and snail shells were processed into powders with controlled granulometry. Drying and milling of hepatopancreas residues yielded organic powders (HPF) with particle sizes predominantly below 200 μm , suitable for soil amendment applications. Snail shell waste was converted into mineral powders (HPO), and selected fractions were subjected to thermal treatments at temperatures between 300 and 600°C. Mass loss trends and physicochemical characterisation (SEM, FTIR, XRF, BET) confirmed structural transformations relevant for nutrient availability and soil interaction. The methodological workflow adopted in this study is summarised in Table 1.

Table 1. Methodological framework and key assessment parameters for the valorisation of snail processing waste within a circular economy.

Step	Material / Fraction	Processing/Test	Key Parameters	Purpose
1	Snail processing waste (<i>Helix pomatia</i>)	Collection and homogenisation	Mass balance	Recovery of secondary resources
2	Organic fraction	Slow maceration (≈ 3 months)	DOC/TOC release	Nutrient solubilisation
3	Liquid macerate	Vacuum filtration	TOC, TN, COD	Nutrient-rich extract
4	Liquid macerate (diluted)	Algal growth inhibition test	72 h exposure, μ_{max} , EC ₅₀	Ecotoxicity screening (<i>Chlorella vulgaris</i> , OECD 201 / ISO 8692)
5	Solid residue	Drying and milling	Particle size	Solid amendment precursor
6	Hepatopancreas powder (HPF)	Drying + grinding	SEM, granulometry	Organic fertiliser fraction
7	Shell powder (HPO)	Milling + calcination	FTIR, XRF, BET	Mineral nutrient carrier
8	Organo-mineral system	Fraction integration	Functional assessment	Closed-loop fertiliser concept

To support safe circular reuse, ecotoxicity screening was incorporated using the freshwater microalga *Chlorella vulgaris* as a standard indicator organism, in accordance with OECD Test Guideline 201 and ISO 8692. Algal growth inhibition assays were conducted over 72 h on selected dilutions of the liquid extract. Growth rate (μ) and maximum specific growth rate (μ_{\max}) were determined, and concentration–response relationships were used to estimate EC₅₀ values. The results enabled the identification of non-inhibitory concentration ranges and supported the differentiation between nutrient stimulation and potential inhibitory effects associated with high organic load.

The outcomes of the *Chlorella vulgaris* assays were further considered in relation to plant-based fitotoxicity tests, providing a complementary assessment framework linking aquatic ecotoxicity with terrestrial plant responses. This integrated evaluation supports the definition of safe application ranges for agricultural reuse and strengthens the environmental robustness of the proposed circular system.

In conclusion, the results demonstrate that snail processing waste can be effectively transformed into bio-based fertilising products that combine nutrient recovery, environmental safety, and circular economy principles. The proposed approach contributes to waste reduction, resource efficiency, and the development of sustainable agricultural inputs with controlled ecological impact.

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