LIFE CYCLOPS: Upcycling polyphenols from industrial olive oil waste

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The LIFE CYCLOPS project is an innovative initiative aimed at the sustainable revalorization of alperujo, a byproduct of olive oil production, within the framework of a circular economy. Olive oil production, primarily concentrated in Mediterranean countries such as Spain, generates substantial quantities of alperujo—over 7 million tons annually in Spain, Italy, and Greece combined. This byproduct is composed of water, olive solids, and fatty residues, posing significant environmental challenges due to its polluting characteristics and recalcitrant properties. These include soil degradation, odor issues, and the presence of polyphenols that hinder traditional biological treatments. LIFE CYCLOPS addresses these issues while capitalizing on the economic potential of polyphenols through advanced technological solutions.

The project has constructed and optimized a pilot plant capable of processing 200 kg/h of alperujo, operational since January 2024. This facility integrates solid-liquid extraction (S/L), phase separation, ultrafiltration (UF), and nanofiltration (NF) technologies to extract and purify polyphenols. Operating at TRL 6–7, the plant demonstrates real-world applications of these methods. The extraction process uses water as a green solvent under optimized conditions, with polyphenols quantified through the Folin-Ciocalteu method and characterized by HPLC-HRMS/MS and HPLC-UV techniques. UF removes suspended solids and high-molecular-weight compounds, clarifying the extract, while NF concentrates polyphenols, achieving a substantial increase in total polyphenolic content (TPC), from 674 mg/L in the UF feed to 1,929 mg/L in the NF concentrate.

In addition to polyphenol extraction, the dephenolized alperujo undergoes anaerobic co-digestion to produce biogas, exemplifying the project's zero-waste philosophy. This process has been validated in real field applications, further reinforcing its environmental and economic viability. The biogas production pathway complements the extraction process, ensuring that all alperujo fractions are valorized.

The project has also advanced the adaptation and purification of polyphenols for various end-user requirements. Flash chromatography has been implemented for the separation and purification of polyphenols, while enzymatic reactions using immobilized lipases and sucrose phosphorylase have been employed to modify their molecular structures. These modifications enhance the suitability of polyphenols for pharmaceutical, nutraceutical, and cosmetic applications. For instance, acylation strategies have been developed to produce novel derivatives with improved antioxidant properties, a crucial advancement for targeted end uses.

The enriched polyphenol products are further stabilized and formulated using techniques such as spray drying, lyophilization, freeze concentration, and encapsulation. These methods have been systematically evaluated to maximize product quality and application potential across multiple industries. This effort ensures that the recovered polyphenols meet the diverse demands of markets such as food, nutraceuticals, pharmaceuticals, and cosmetics. Moreover, the formulations aim to enhance bioavailability, shelf life, and functional properties, broadening the application scope of the products.

The project's technological innovations are complemented by extensive impact assessments and replicability studies. The pilot plant's operations are monitored to collect experimental data, which supports environmental, technical, and economic evaluations. This data guides the potential transferability of the process to other sectors, such as the wine industry, where similar byproducts can be valorized. Studies on scalability and market integration have been initiated to ensure that the solutions developed under LIFE CYCLOPS can be adopted across industries.

In conclusion, LIFE CYCLOPS demonstrates the feasibility and benefits of transforming agrifood residues into valuable bioproducts and energy through innovative and sustainable technologies. By integrating advanced extraction, purification, and bioconversion methods, the project sets a benchmark for zero-waste solutions in the agrifood industry. The comprehensive approach to technology development, optimization, and application highlights the significant potential of polyphenol recovery to enhance environmental sustainability and create new market opportunities.

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