SUSTAINABLE PRODUCTION OF ANTIOXIDANTS AND NATURAL PIGMENTS FROM OLIVE LEAVES

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RESUMEN

The "*Analytical and Circular (Bio)Chemistry*" research group (bioCir) at the University of Alicante has developed an integrated valorisation process for olive leaves (Olea europaea L.) based on an ultrasonics-assisted cascade sequential extraction scheme. Starting from a single agricultural residue stream, the process yields two distinct bioactive fractions: an extract enriched in antioxidant phenolic compounds and an extract rich in chlorophyll pigments.

The key differentiating element of the process is that the solid residue generated after the first extraction stage is not discarded but reincorporated as the feedstock for the second stage, leveraging the structural modifications induced in the plant matrix to enhance pigment recovery efficiency. This cascade biorefinery approach maximises the yield of bioactive compounds per kilogram of biomass processed, minimises solid waste generation, and is scalable using equipment already available in the olive-processing industry.

The technology, protected by a national patent application, has been validated at laboratory scale. The resulting extracts have demonstrated applicability across the functional food, nutraceutical, cosmetics, and active packaging sectors. Industrial partners interested in its commercial exploitation are sought.

INTRODUCCIÓN

The global transition towards circular economy models and the implementation of strategic frameworks such as the UN's 2030 Agenda have placed growing pressure on the agri-industrial sector to transform waste management systems into resource valorisation processes. The olive oil industry, which accounts for approximately 70% of global olive oil production, generates over 33 million tonnes of residual biomass annually from pruning and grove maintenance activities. Despite its intrinsic potential for the recovery of high-value bioactive compounds, this biomass is predominantly managed through direct disposal or incineration — practices that compromise sustainability targets and erode the sector's economic competitiveness.

Existing solutions for the recovery of these compounds face significant operational bottlenecks. Conventional solid-liquid extraction processes are characterised by lengthy production cycles, high consumption of organic solvents, and the risk of thermal degradation of heat-sensitive compounds. Non-conventional technologies, while promising, often encounter scalability barriers due to the complexity of their operating conditions. The most critical inefficiency, however, lies in the prevailing technical paradigm: the vast majority of current processes and patents are designed to recover a single bioactive fraction — typically phenolic compounds — treating the resulting solid residue as a final waste stream with no additional commercial value.

This “single-extraction” paradigm has direct economic and operational consequences: when biomass is discarded after an initial processing step, high-value industrial compounds — such as chlorophylls and carotenoids — are irrecoverably lost, resulting in a substantial reduction in value generated per tonne of processed raw material. A significant technology gap therefore persists between the massive availability of olive-sector by-products and the technical capacity to process them in an integrated manner, underscoring the urgent need for a new approach capable of enabling the sequential and efficient recovery of multiple bioactive fractions from the same plant matrix.

DESCRIPCIÓN TÉCNICA

The bioCir research group at the University of Alicante has developed an integrated valorisation process for olive leaves (Olea europaea L.) aimed at the sequential recovery of distinct bioactive fractions from the plant biomass. The process is a solid-liquid extraction method that, from a single raw material, yields two compositionally differentiated fractions through a series of consecutive, ordered stages. The process design ensures that the solid residue generated after the first extraction is not discarded, but instead serves as the starting substrate for the subsequent stage, establishing a cascade valorisation scheme aligned with the principles of plant-based biorefineries.

The process comprises four consecutive stages: an initial biomass preparation step, a second stage dedicated to the extraction of phenolic compounds, a third stage for the recovery of the resulting solid residue, and a fourth stage for the extraction of chlorophyll pigments. Both the second and fourth stages are assisted by ultrasound — a technology that, when applied to the solid-liquid system, promotes mass transfer from the plant matrix to the solvent without altering the fundamental nature of the extraction process. A different extractive solvent is used in each stage, selected on the basis of the physicochemical properties of the target compounds.

The process yields two bioactive extracts of different nature: one enriched in antioxidant phenolic compounds, obtained in the second stage, and one rich in photosynthetic chlorophyll pigments, recovered in the fourth stage from the previously processed solid residue. Notably, the first extraction stage not only recovers the phenolic compounds present in the biomass, but also favourably conditions the structural properties of the resulting solid matrix, thereby enhancing the efficiency of the subsequent extraction stage. In this way, the process addresses the problem of the inefficient use of olive leaf residual biomass, transforming an agricultural by-product into a multi-fraction source

VENTAJAS Y ASPECTOS INNOVADORES

ADVANTAGES OF THE TECHNOLOGY

The main advantages of the developed process are as follows:

Intrinsic Process Advantages

- **Maximised yield per unit of biomass**: Reuse of the solid residue as the substrate for the second stage significantly increases the quantity of bioactive compounds recovered per kilogram of processed raw material.
- **Synergy between extraction stages**: The first extraction favourably conditions the structure of the plant matrix, improving the efficiency of chlorophyll pigment recovery in the subsequent stage.
- **Reduced processing times and solvent consumption**: Ultrasonic assistance significantly shortens production cycles and minimises the volume of solvents required compared to conventional methods such as maceration or Soxhlet extraction.
- **Preservation of extract quality**: The process operating conditions reduce the risk of thermal degradation of the most sensitive bioactive compounds, safeguarding the integrity of the resulting products.
- **High reproducibility**: Systematic experimental optimisation of the process ensures consistent extract quality — a critical requirement for integration into industrial formulations.

Environmental and Sustainability Advantages

- **Minimisation of solid waste**: Integral biomass valorisation drastically reduces the generation of final waste streams, contributing to more efficient and responsible management of agricultural by-products.
- **Alignment with circular economy and sustainability goals**: The process is grounded in green chemistry principles and supports the strategic objectives of the 2030 Agenda, facilitating compliance with prevailing sustainability regulatory frameworks.
- **Immediate industrial scalability**: The process design is compatible with ultrasound equipment and technologies already available in the olive-processing sector, without requiring investment in highly specialised infrastructure.

Commercial and Market Advantages

- **Product portfolio diversification**: The process simultaneously yields antioxidant extracts and natural pigments, broadening the range of marketable ingredients for sectors such as functional food, cosmetics, and nutraceuticals.
- **Reduced operational costs**: Converting agricultural residues into new value streams reduces waste disposal costs and optimises the overall profitability of the olive supply chain.
- **Positioning in high-demand markets**: The ability to supply clean-label natural bioactive ingredients strengthens the company’s competitive standing in markets facing increasing regulatory pressure on synthetic additives.
- **Conversion of an environmental liability into an economic asset**: By transforming a large-scale, problematic agricultural

residue into a source of high-value-added products, the technology turns an operational challenge into a sustainable strategic advantage.

KEY INNOVATIVE ASPECTS

The primary innovative aspect of this process is the introduction, for the first time, of a cascade sequential extraction scheme applied to olive leaves that integrates — within a single process — the recovery of phenolic compounds and the subsequent extraction of chlorophyll pigments from the solid residue generated in the first stage.

Unlike existing methods and patents, which treat the post-extraction solid residue as a final waste stream, this process reincorporates it as an active substrate for a second valorisation stage, fundamentally redefining its role within the process.

The process is built on the principle that the first extraction stage does not merely recover phenolic compounds, but structurally modifies the plant matrix in a way that increases the accessibility of chlorophyll pigments in the subsequent stage. This inter-stage interaction constitutes a technically differentiating element not previously described in the state of the art.

ESTADO ACTUAL

The technology is currently developed at laboratory scale, having been validated through experimental studies that include the systematic optimisation of process parameters. The results obtained demonstrate the technical feasibility of the process and its capacity to generate standardised, reproducible extracts with consistent yields across both bioactive fractions.

As the next development milestone, the research group plans to carry out process validation at pilot scale and its application in specific industrial settings. The priority sectors identified for this validation phase are functional food, nutraceuticals, and cosmetics, given the high demand for natural antioxidant ingredients and plant-derived pigments compatible with the extracts produced by this process.

APLICACIONES DE LA OFERTA

The extracts obtained through this process are applicable across a range of industrial sectors, determined by the nature and functional properties of each bioactive fraction.

The **extract enriched in antioxidant phenolic compounds** is primarily applicable in the following sectors:

- **Functional food and food technology:** as a natural antioxidant ingredient for the formulation of functional foods, plant-based preservatives, or protective agents against lipid oxidation in processed products.
- **Nutraceuticals and dietary supplementation**: as a raw material for the development of dietary supplements and nutraceutical products with antioxidant activity and potential health benefits.
- **Cosmetics and dermopharmac**y: as a functional active in cosmetic and dermatological formulations targeted at protection against cutaneous oxidative stress.
- **Active packaging materials**: as a functional additive in the development of packaging materials with antioxidant properties for food preservation.

The **extract enriched in chlorophyll pigments** is applicable in the following areas:

- **Food industry**: as a plant-derived natural colourant to replace synthetic additives, in a context of increasing regulatory restrictions on the latter.
- **Cosmetics**: as a natural functional pigment in make-up, skincare, and hair care formulations.
- **Nutraceuticals and dietary supplementation**: as a functional ingredient with antioxidant properties complementary to those of phenolic compounds.
- **Agriculture**: as a component in the formulation of organic-based biostimulants and foliar fertilisers, given the structural relationship between chlorophylls and plant physiological processes.

COLABORACIÓN BUSCADA

The bioCir research group at the University of Alicante seeks to establish licensing agreements, technology transfer agreements, and joint research agreements with companies interested in incorporating this process into their production operations or in participating actively in subsequent validation and development stages.

Under a **licensing agreement**, the group contemplates the grant of rights to use the technology to companies with the industrial capacity to implement it and to commercialise the resulting extracts.

Under a **technology transfer agreement**, the group offers the transmission of the technical know-how associated with the process, including the support necessary for its correct implementation in the industrial partner's production environment.

Under a **joint research agreement**, the group is open to collaborating with industrial partners on pilot-scale process validation and on its adaptation to specific applications or sectors, drawing on its expertise in extraction process optimisation and bioactive

fraction characterisation.

Priority collaboration areas identified by the research group include:

- Process validation at pilot scale.
- Industrial scale-up of the process.
- Development of functional ingredients and commercial formulations.
- Evaluation of applications in food and cosmetic matrices.
- Development of valorisation solutions for olive-sector by-products.

The group is primarily seeking industrial partners from the following sectors:

- Olive-sector companies interested in the integrated valorisation of their agricultural by-products.
- Nutraceutical supplement and functional food manufacturers requiring standardised natural antioxidant ingredients.
- Natural cosmetics and dermopharmacy companies focused on formulation with plant-derived actives.
- Manufacturers of natural colorants or functional ingredients for the food industry.
- Companies in the crop protection and agricultural biostimulant sector interested in developing organic-based formulations from plant biomass.
- Companies specialising in agricultural biomass biorefining or in the management and valorisation of agri-food sector residues.

DERECHOS DE PROPIEDAD INTELECTUAL

This technology is protected by a **patent application**.

- *Patent title: "Process for the extraction of bioactive compounds from olive leaves (Olea europaea L.)"*
- *Application number: P202630578*
- *Filing date: 20 April 2026*

SECTORES DE APLICACIÓN (2)

Agri-food and Fisheries
Chemical Technology