AGRITECH

National Research Centre for Agricultural Technologies

BOtanical REsources for ALternative battEries - "BO.RE.AL.E."

AMBITO: NUOVE MOLECULE, PRODOTTI E PROCESSI AD ALTRO VALORE AGGIUNTO PER LA VALORIZZAZIONE DI RIFIUTI, SCARTI, SOTTOPRODOTTI E COPRODOTTI AGRICOLI O PER L'AGRICOLTURA

ASCLA SOCIETA' COOPERATIVA IMPRESA SOCIALE (Leader)

RADICE CUBICA S.R.L. (Partner)

UNIVERSITÀ DEL SALENTO (Partner)

Deliverable: D1.2

Deliverable title: Dataset of suitable agri-waste raw material and physical/chemical proprieties

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2. EXECUTIVE SUMMARY

This document, Deliverable D1.2 – Dataset of Raw Materials from Agricultural By-products and Physical-Chemical Characteristics, represents the outcome of the activities carried out within Task 1.2 of the BO.RE.AL.E. project – BOtanical REsources for ALternative battEries, funded under the National Recovery and Resilience Plan (PNRR), Mission 4 – Component 2 – Investment 1.3.

The deliverable is in direct continuity with D1.1, which enabled the mapping and classification of the main agricultural and agri-food supply chains in Southern Italy, identifying their potentially valuable by-products. D1.2 focuses on the subsequent phase: the selection, classification, and preliminary characterization of the most promising biomasses, according to the three technological pathways defined by the project: production of carbon dots, extraction of redox molecules, and generation of micro/nano-structured carbons.

The methodological approach integrated bibliographic sources, analysis of data collected in the field from agri-food companies, and functional screening conducted by the research group of the University of Salento. The selection criteria considered physical-chemical properties (moisture content, lignocellulosic composition, content of phenolic compounds, redox potential), territorial availability of the biomasses, and their environmental, logistical, and economic relevance.

In total, 67 agri-food supply chains were analyzed, from which 10 biomasses of interest were selected, representative of the main commodity categories identified in Task 1.1 (tree crops, horticultural crops, cereals, legumes, and medicinal/aromatic plants). For each, a structured technical database was compiled, reporting the values of the main physical-chemical variables useful for assessing their suitability for subsequent transformations into functional materials.

This work constitutes a fundamental knowledge base for the experimental activities planned in WP2 and represents a replicable model for circular bioeconomy initiatives, in line with the objectives of the European Green Deal and the innovation pathways promoted by the PNRR. Furthermore, the collected data enable a preliminary assessment of the environmental and logistical impacts of the analyzed supply chains, anticipating the systemic evaluations planned in WP4.

3. INTRODUCTION

The BO.RE.AL.E. project (BOtanical REsources for ALternative battEries) aims to develop an innovative supply chain for the production of advanced materials derived from agricultural and agro-industrial by-products, contributing significantly to the transition toward sustainable, circular, and low-impact production models. The project lies at the intersection of green chemistry, material science, and sustainable agro-industrial development, with the objective of generating technological solutions for electrochemical energy storage using renewable resources.

Following the mapping of agricultural and agri-food supply chains in Southern Italy carried out in Task 1.1, Task 1.2 was tasked with identifying, classifying, and characterizing the most promising by-products from a chemical-physical perspective, particularly in terms of their suitability for conversion into high-performance functional materials. The main valorization pathways considered include the production of redox-active molecules (quinonoid, flavonoid, anthraquinone compounds), the synthesis of carbon dots (CQDs), and the generation of micro/nano-structured carbons usable as electrodes in thin-film devices.

This activity is part of a broader framework addressing scientific, environmental, and economic challenges: reducing the accumulation of organic waste, increasing the territorial competitiveness of the bioeconomy in Southern Italy, and developing scalable models for the valorization of agricultural residues, in line with the objectives of the European Green Deal and the Italian National Recovery and Resilience Plan (PNRR).

The agricultural production in Southern Italy, highly diversified in terms of cultivated species and seasonal distribution, generates a significant quantity of residual biomass that is often not exploited. However, their use in advanced processes requires a careful evaluation of chemical-physical properties, stability, availability, and compatibility with technological transformation processes. This deliverable represents the first step toward that evaluation, providing a technical overview of the most relevant biomasses and outlining the scientific and applicative criteria used for their selection.

4. METHODOLOGY

The methodology adopted for Task 1.2 of the BO.RE.AL.E. project followed a structured, multidisciplinary, and integrated approach aimed at the identification, classification, and preliminary characterization of residual biomasses with valorization potential in the production of functional materials for electrochemical energy storage. The process was divided into five operational phases, designed to ensure scientific rigor, methodological coherence with Task 1.1, and maximum interoperability with the experimental activities planned in WP2.

Preliminary screening and data consolidation

In line with the results obtained in Task 1.1, a preliminary list of waste biomasses and by-products was defined, originating from the main agricultural and agro-industrial supply chains in Southern Italy. For each material, systematic information was collected on territorial origin, processing context, seasonality, and agronomic characteristics. The data were obtained through three main sources:

- technical sheets and field observations collected from production and processing companies;
- interviews with agronomists and professionals from the agro-industrial sector;
- review of national and international scientific and technical literature.

Classification by functional destination

Each biomass was assessed for its suitability within three specific valorization pathways:

- extraction of redox molecules of plant origin (e.g., quinones, flavonoids, tannins);
- synthesis of carbon quantum dots (CQDs);
- production of micro- or nano-structured carbons for thin electrodes.

The classification was carried out by cross-referencing chemical composition data with bibliographic evidence and preliminary laboratory analyses. The main functional chemical precursors (e.g., lignin, hemicellulose, phenolic compounds), compatibility with experimental technological processes, and application potential in relation to the project's objectives were considered.

Chemical-physical characterization

Candidate biomasses were subjected to a comparative evaluation of their main chemical-physical properties. For each material, the following parameters were analyzed:

- moisture content;
- lignocellulosic composition (percentages of lignin, cellulose, and hemicellulose);
- presence of bioactive secondary compounds (phenols, flavonoids, quinones);
- granulometry and bulk density;
- storage stability and logistical compatibility.

These data were obtained through bibliographic analysis, technical-scientific databases, and, where possible, validated through preliminary experimental screening conducted by the WP2 research group at the University of Salento using standardized protocols.

Scoring and selection of priority biomasses

To identify the most promising sources, a semi-quantitative scoring system was implemented based on four main criteria:

- territorial and seasonal availability of the biomass;
- reactive potential in relation to the target valorization;
- logistics of procurement and processing;
- technical compatibility with WP2 processes.

The analysis led to the selection of 10 priority biomasses, chosen from among the 67 supply chains mapped in Task 1.1, which demonstrated high technological potential and good logistical accessibility. These biomasses represent the operational core for subsequent experimental activities.

Structuring of technical information

All collected data were organized into a structured archive, following interoperability standards and ready for integration into subsequent WP2 (technological experimentation) and WP4 (sustainability analysis). For each biomass, the following were recorded:

- origin and source supply chain;
- key chemical-physical parameters;
- functional destination (redox, carbon dots, carbons);
- bibliographic references and primary sources;
- feasibility assessment for sourcing and processing.

The resulting collection represents a solid knowledge base, useful not only for the advancement of the BO.RE.AL.E. project but also as a replicable model for future initiatives in the field of circular bioeconomy and sustainable agricultural waste valorization.

5. RESULTS AND DISCUSSION

5.1 Functional classification of biomasses

The results of Task 1.2 represent the outcome of a structured process of selection and technical analysis of residual biomasses originating from the main agricultural and agro-industrial supply chains of Southern Italy, previously mapped in Deliverable D1.1. Starting from 67 identified supply chains, 10 priority biomasses were selected based on their chemical composition, territorial availability, compatibility with the proposed valorization processes, and potential for transformation into functional materials.

Below is a summary table mapping the by-products from the 67 supply chains:

Filiera	Sottoprodotti principali	Potenziale applicativo
Olivo	Sanse, acque di vegetazione, rami e foglie	Polifenoli, biochar, compost
Vite	Vinacce, vinaccioli, raspi, fecce	Estrazione fenolica, carbonizzazione
Agrumi	Bucce, semi, polpa, oli essenziali esausti	Flavonoidi, oli essenziali, biomasse

Mandorlo	Gusci, pellicole/cuticole	Carbonizzazione, combustibile naturale
Pistacchio	Gusci, residui di sgusciatura	Biochar, polveri per cosmetica
Nocciolo	Gusci, foglie	Carbonizzazione, compost
Noce	Gusci, malli	Fertilizzanti, combustibile
Castagno	Gusci, malli, foglie	Compost, tannini, bioadsorbenti
Fico	Foglie, scarti di lavorazione, bucce	Compost, fermentazione
Fico d'India	Bucce, pale scartate, semi	Bioplastiche, bioenergia
Ciliegio	Raspi, noccioli	Bioadsorbenti, olio da nocciolo
Albicocco	Noccioli, bucce	Carbonizzazione, enzimi
Pesco	Noccioli, bucce	Estrazione di oli, fermentazione
Melograno	Bucce, semi	Polifenoli, biomassa per fermentazione
Avocado	Nocciolo, bucce	Compost, oli naturali
Cachi	Buccia, residui di lavorazione	Compost, estrazione fenolica
Pomodoro	Bucce, semi, acqua di vegetazione	Lycopene, biochar, biomassa umida
Carciofo	Foglie esterne, gambi	Compost, estrazione di antiossidanti
Melanzana	Buccia, semi, peduncoli	Compost, bioenergia
Peperone	Semi, pericarpo	Estratti fenolici, bioenergia
Zucchina	Scarti freschi	Compost, foraggio
Cipolla	Tuniche, radici	Compost, uso zootecnico
Lattuga	Foglie scartate	Foraggio, compost
Cavolfiore	Foglie, torsoli	Bioenergia, fermentazione
Patata	Bucce, acqua di lavaggio	Bioetanolo, biofertilizzanti
Fagiolino	Baccelli	Compost, biomassa fermentabile
Melone	Bucce, semi	Compost, estrazione di olio
Sedano	Foglie, gambi esterni	Compost, fermentazione
Bietola	Foglie, radici scartate	Uso zootecnico, fermentazione

Carota	Scarti di lavaggio	Compost, bioetanolo
Cetriolo	Scarti freschi	Uso zootecnico, compost
Finocchio	Foglie esterne	Compost, estrazione di oli
Spinacio	Foglie scartate	Compost
Barbabietola	Foglie, polpa	Bioetanolo, alimentazione
Aglio	Tuniche, radici	Compost, bioadsorbenti
Girasole	Paglia, capolini	Carbonizzazione, biocombustibili
Grano duro	Paglia, crusca	Biochar, substrato agricolo
Grano tenero	Paglia, glume	Compost, bioenergia
Orzo	Paglia, sottoprodotti di maltazione	Biochar
Avena	Paglia	Compost, bioenergia
Mais	Tutoli, foglie	Biogas, substrati
Riso	Lolla, pula, paglia	Bioadsorbenti, carbone attivo
Farro	Glume, paglia	Compost, bioenergia
Sorgo	Stocchi, semi	Compost, zootecnia
Ceci	Baccelli, crusca	Compost, mangimi
Lenticchie	Baccelli, polvere	Compost, fermentazione
Fagioli	Baccelli	Compost, bioenergia
Cicerchie	Baccelli, crusca	Compost, fertilizzanti
Lupini	Buccia, acqua di lavorazione	Bioadsorbenti
Fave	Baccelli	Compost, fermentazione
Piselli	Baccelli, scarti	Compost
Soia	Paglia, tegumento	Compost, carbonizzazione
Canapa	Canapulo, foglie, infiorescenze, steli	Biochar, estratti, carbon dots
Origano	Residui floreali, rami	Idrolati, compost
Bambù	Foglie, frammenti di culmi, polvere	Biomateriali (pannelli, tessuti), compost, biochar
Rosmarino	Scarti fogliari, steli, residui oleosi	Estratti funzionali, integratori, cosmesi, ammendanti
Alloro	Foglie invendibili, ramaglie	Oli essenziali tecnici, insetto-repellenti, biomassa combustibile

Zafferano	Stimmi esausti, fiori	Cosmesi, estrazione fenolica
Liquirizia	Radici esauste, foglie	Compost, estratti
Aloe	Foglie esterne	Cosmesi, compost
Cumino nero	Gusci, semi danneggiati, residui di pressatura	Mangimi funzionali, oleoliti, cosmesi, integratori naturali
Calendula	Infiorescenze	Compost, cosmetica
Lavanda	Infiorescenze esauste	Idrolati, bioenergia
Elicriso	Fusti, infiorescenze	Cosmesi, carbonizzazione
Genziana	Radici scartate	Compost, bioenergia
Salvia	Residui floreali, foglie	Cosmesi, compost
Bergamotto	Bucce, oli esausti	Bioenergia, oli residuali

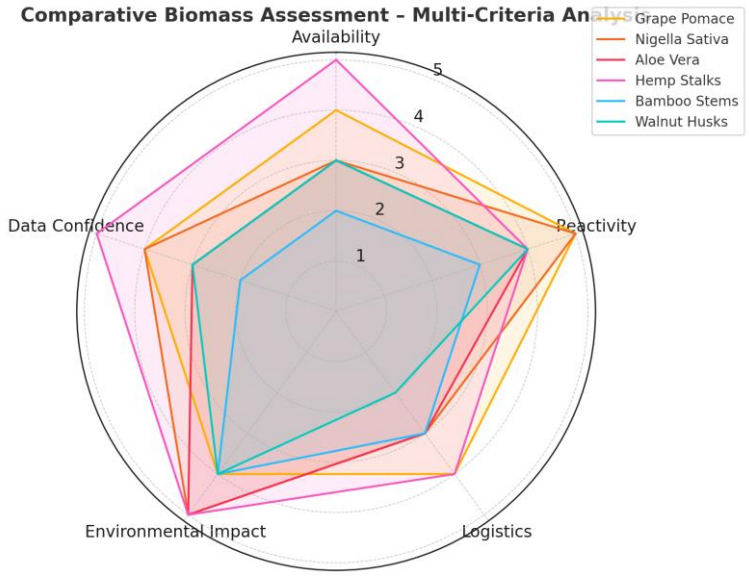
The selected biomasses were assigned to three different technological valorization pathways: (i) production of carbon dots, (ii) extraction of redox molecules, and (iii) synthesis of micro- and nano-structured carbons. This classification was conducted based on physico-chemical analysis and data collected during the screening phase, validated through scientific literature and, where possible, preliminary experimental trials conducted by the academic partner.

Below is the functional classification of the selected biomasses. The identified materials have been categorized according to the three main valorization purposes outlined in the project:

FINALITÀ	MATERIALI DI INTERESSE
Produzione di carbon dots	Vinacce, Bucce di pomodoro, Bucce e parte interna del melograno, Foglie esterne del fiore di carciofo
Estrazione di molecole redox	Nigella sativa (timochinone), Bucce e parti interne della noce (antrachinoni), Aloe vera (antrachinoni)
Produzione di carboni micro-strutturati	Steli di canapa, Steli di bambù, Steli e foglie di alloro (filiera oli essenziali)

5.2 Comparative Evaluation and Observations

To support the selection process, a multi-criteria analysis was conducted based on five evaluation dimensions: availability, chemical reactivity, logistics, environmental impact, and data reliability. The results were visualized using a radar chart (Fig. 1), which compares the relative performance of five representative biomasses.



The analysis shows that grape pomace and hemp stalks represent the most balanced options, due to their wide availability, good reactivity, and environmentally sustainable profile. Laurel also demonstrates high compatibility with carbonization processes, while *Nigella sativa*, although presenting logistical challenges, offers excellent redox potential due to the presence of thymoquinone. Bamboo culms, despite being chemically promising, raise issues of scalability and sourcing.

Particular attention was paid to the territorial availability and proximity of the biomasses to processing centers. Biomasses already integrated into existing industrial supply chains (such as grape pomace and tomato peels) offer a logistical advantage and lower environmental impact compared to those requiring dedicated chains (such as bamboo or *Nigella*).

Lastly, a qualitative reliability index was assigned to the data available for each biomass, based on the maturity of agronomic studies and the availability of compositional databases. This information serves as a key reference for the transition to WP2, where experimental tests for valorization and functional characterization are initiated.

6. CONCLUSIONS

Deliverable D1.2 completes the work cycle foreseen by WP1 of the BO.RE.AL.E. project, supporting the transition from the reconnaissance phase to the experimental phase. The activity led to the selection, classification, and description of ten agro-industrial biomasses with valorization potential, starting from an initial set of 67 agricultural and processing supply chains mapped in Task 1.1.

The selection was carried out based on scientific, technical, and logistical criteria, through the integration of bibliographic sources, preliminary functional analyses conducted by the University of Salento, and field data collected from companies and sector operators. The selected biomasses were grouped into three main valorization pathways consistent with the project's objectives:

- **Carbon dots**: carbon-based nanostructured materials for applications in sensing, optoelectronics, and diagnostics;
- **Redox molecules**: bioactive compounds potentially usable in energy storage systems;
- **Micro/nano-structured carbons**: porous materials intended for the fabrication of electrodes for electrochemical devices.

The selected biomasses originate from horticultural, fruit, woody, and medicinal crop supply chains widely present in Southern Italy, ensuring source diversification and territorial availability. In addition to chemical and physical properties, the analysis considered parameters such as seasonality, logistical availability, proximity to processing centers, and stability during collection and storage processes.

The work resulted in the construction of a structured set of data and information, which serves as a reference for the experimental activities foreseen in WP2. In this phase, the selected biomasses will undergo extraction, purification, and characterization treatments to evaluate their suitability for use in energy storage devices.

Moreover, the applied methodology and the organization of the information collected offer potential for extension to other territorial or thematic contexts, facilitating the application of agricultural by-product valorization models within local supply chains aimed at sustainability and technological innovation.