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Editorial

Unlocking the Potential of Agri-Food Waste for Innovative Applications and Bio-Based Materials

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Abstract

The Special Issue "Unlocking the Potential of Agri-Food Waste for Innovative Applications and Bio-Based Materials" brings together recent advances and emerging strategies for the valorization of agri-food residues. This Editorial provides an overview of the contributions included in the Special Issue, highlighting innovative approaches that convert waste streams into valuable bio-based materials, chemicals, and products. The collected works demonstrate how hydrodynamic, chemical, biological, and catalytic processes can be integrated to achieve sustainable waste management and circular resource recovery. By summarizing the main findings and perspectives, this Editorial emphasizes the growing relevance of agri-food waste valorization within the framework of the circular bioeconomy and encourages further interdisciplinary collaboration to accelerate the transition toward sustainable production systems.

1. Introduction

The twenty-first century is witnessing an unprecedented convergence of two major global challenges: the overproduction of waste and the unsustainable consumption of natural resources. Agriculture and food processing industries, although essential to human survival, are among the largest generators of waste streams. Crop residues, food processing by-products, expired or unsold food, and lignocellulosic biomass are produced in massive amounts each year, with a large fraction underutilized or improperly disposed of. According to the Food and Agriculture Organization (FAO), nearly one-third of the food produced globally for human consumption—approximately 1.3 billion tons per year—is wasted. This waste not only represents an ethical and social issue but also translates into severe environmental consequences, including greenhouse gas emissions, soil and water pollution, and resource depletion [1,2]. In this context, the concept of a circular bioeconomy has emerged as a paradigm shift from the traditional linear "take–make–dispose" model. The valorization of agri-food waste is at the core of this approach, aiming to transform residues into valuable resources and reduce dependence on fossil-based feedstocks. Emerging technologies enable the conversion of agricultural residues into bio-based materials, renewable energy, nutraceuticals, biodegradable composites, or innovative products for agricultural practices [3–5]. These strategies also contribute to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 ("Responsible Consumption and Production") and SDG 13 ("Climate Action") [6]. This Special Issue, "Unlocking the Potential of Agri-Food Waste for Innovative Applications and Bio-Based Materials", was conceived to capture recent advances in this vibrant field of research. The publications in this Special Issue highlight how different waste streams can be upgraded through thermal,

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chemical, and biological approaches, offering sustainable alternatives to conventional practices. By presenting either experimental studies or reviews, this Special Issue underlines the transformative power of science and technology in addressing one of the most pressing environmental challenges of our time.

Agri-Food Waste as a Strategic Resource

Agri-food residues encompass a wide variety of materials, from lignocellulosic biomass such as husks, stalks, and shells to protein-rich and lipid-rich by-products of food processing. Their heterogeneous composition makes them suitable for a broad spectrum of valorization routes [7,8]. Among the most prominent technological strategies are

- Thermochemical processes, such as pyrolysis, which can convert biomass into biochar, syngas, and bio-oils with high energy potential [9].
- Biotechnological routes, including fermentation and enzymatic treatments, that enable the extraction or synthesis of biopolymers and bioactive compounds [10].
- Material science approaches, in which natural fibers and biopolymers are integrated into composites or packaging materials to replace petroleum-derived plastics [11].
- Nutraceutical and pharmaceutical valorization, where secondary metabolites from agri-food waste provide bioactive compounds with antimicrobial, antioxidant, or therapeutic functions [12].

The integration of these approaches exemplifies the vision of a circular economy: using what is conventionally regarded as waste to generate high-value products, thereby closing the loop of production and consumption [13].

2. Contributions in This Special Issue

The articles collected in this Special Issue describe the multifaceted opportunities of agri-food waste valorization, spanning applications in energy, antimicrobial compounds, biodegradable materials, and sustainable agricultural inputs.

2.1. Residues from Oil-Pressing Processes as Biochar for Alternative Fuels

The authors investigated the pyrolysis of oilseed press cakes from fennel flower, rapeseed, flax, evening primrose, milk thistle, and hemp. Biochar derived from these residues can reach calorific values as high as 27 MJ kg^{-1}—comparable to high-grade fossil fuels—and exhibited reduced emissions of carbon monoxide, nitrogen oxides, and sulfur dioxide [14].

2.2. Chestnut Burrs as a Source of Antimicrobial Bioactive Compounds

Chestnut burrs, which are usually discarded as waste, were shown to contain gallic acid, quinic acid, protocatechuic acid, brevifolin carboxylic acid, and ellagic acid. The study demonstrated modest antibacterial activity, particularly against *Enterococcus faecalis*, with a minimum inhibitory concentration (MIC) of 64 µg/mL. Complementary in silico analyses provided insights into molecular targets, supporting potential drug discovery applications [15].

2.3. The Role of Natural Plant and Animal Fibers in PLA Composites

The incorporation of flax and sheep wool fibers into polylactic acid (PLA)-based composites improved mechanical properties (flax) and accelerated degradation in soil (wool). Although wool fibers promoted biodegradability, excessive wool content reduced mechanical strength, highlighting the trade-off between durability and degradability in material design [16].

2.4. Harnessing Agri-Food Waste as a Source of Biopolymers for Agriculture

The extraction and synthesis of natural biopolymers from lignin, cellulose, pectin, starch, and chitosan were reviewed. Applications include mulching films, hydrogels, nanocarriers, soil stabilizers, and seed coatings. These sustainable polymers can replace fossil-based plastics in agriculture, embodying a circular economy approach [17].

3. Challenges and Future Perspectives

While the works in this Special Issue clearly demonstrate the potential of agri-food waste valorization, significant challenges remain to be addressed. These include economic feasibility and scale-up as current strategies are often demonstrated at pilot scale, requiring cost-effective processes, robust supply chains, and supportive policies for industrial deployment [18]; the heterogeneity of raw materials, as agri-food waste streams vary widely in composition, complicating standardization and requiring adaptive technologies; regulatory frameworks and safety concerns, as applications in food, feed, or biomedical sectors demand strict compliance with safety standards and clear regulatory pathways [19]; and integration into circular systems, as valorization must be integrated into existing agricultural and industrial systems, optimizing energy, water, and material flows holistically [20]. Future studies will benefit from interdisciplinary research, hybrid technologies combining thermochemical and biological routes, and the integration of digital tools such as life-cycle assessment and artificial intelligence. Societal acceptance and consumer awareness will also be critical to the success of waste-derived products.

4. Conclusions

This Special Issue demonstrates that agri-food waste is not an endpoint but a starting point for innovation. From biochar fuels to antimicrobial extracts and from biodegradable composites to agricultural biopolymers, these contributions underscore the versatility of waste streams as sustainable feedstocks. Valorization of agri-food waste reduces environmental burdens, creates value-added products, and promotes circular economy practices. At the same time, continuous innovation, interdisciplinary collaboration, and supportive policies are essential to overcoming existing barriers.

As Guest Editors, we extend our gratitude to all authors for their contributions, to reviewers for their constructive feedback, and to the editorial staff for their support. It is our hope that this Special Issue inspires further research and collaboration to transform agri-food waste into a springboard for sustainable progress.

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