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EDITED AND REVIEWED BY
Maria Pilar Bernal,
Spanish National Research Council
(CSIC), Spain

*CORRESPONDENCE
Saurabh Singh
✉ srb0484@gmail.com

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Editorial: Sustainability in integrated food systems for biovalorization and circular bioeconomy

Saurabh Singh^{1*}, Durgesh Kumar Jaiswal², Raj Morya³,
Jay Prakash Verma⁴ and Rajesh K. Sani⁵

¹School of Chemical and BioPharmaceutical Sciences, Technological University Dublin, Dublin, Ireland, ²Department of Biosciences, Graphic Era (Deemed to be University), Dehradun, Uttarakhand, India, ³Lbe Laboratoire De Biotechnologie De L'environnement, INRAE, Narbonne, France, ⁴Plant-Microbe Interaction Lab, Institute of Environment and Sustainable Development (IESD), Banaras Hindu University, Varanasi, Uttar Pradesh, India, ⁵Karen M. Swindler Department of Chemical and Biological Engineering, and Chemistry, Biology and Health Sciences, South Dakota School of Mines, Rapid City, SD, United States

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Editorial on the Research Topic

Sustainability in integrated food systems for biovalorization and circular bioeconomy

Sustainability in integrated food systems is becoming increasingly critical, particularly in conjunction with biovalorization and the circular bioeconomy. The exponential increase in world population and rise in demand for food are overwhelming the food production and waste management systems (Silveira et al., 2026). Scientists around the world are trying to address these challenges by using novel bioprocessing techniques in agriculture and food processing. These techniques involve the biovalorization of organic residues into valuable products such as biofuels and bioproducts. Biovalorization of waste aligns well with the concept of circular bioeconomy, which primarily focuses on utilizing resources more efficiently, reducing waste, and maintaining closed-loop material and energy flows with minimal environmental impact.

This Research Topic was launched within the Waste Management in Agroecosystems section of *Frontiers in Sustainable Food Systems* to catalyze scientific advancements by integrating novel insights, methodologies, and applications that enhance knowledge and innovation in this field. The call for articles sought submissions on waste management through biovalorization, the shift toward a circular economy in food production and processing, and the crucial role of policies in supporting these transitions. Key questions related to reducing greenhouse gas emissions through biovalorization include: Which strategies are most effective for implementing circular principles in food systems? How can governments and markets create conditions for these practices to thrive? The contributions in this Research Topic provide answers to several of these points. They cover topics such as lignin depolymerization, nutrient recovery, and other technical advances, but also include reviews and discussions on the policy and social aspects of food system transitions. This underscores the necessity of integrated approaches that combine both science and policymaking to make circular food systems a reality. This Research Topic

of articles advances the vision of a circular bioeconomy that not only minimizes waste and regenerates products by integrating the waste streams into production systems, thereby reducing environmental pressures.

The valorization of organic waste streams in soil-plant systems

Nicastro et al. explored how far human urine derivatives can be used in circular agriculture, and they tested them on lettuce in soilless systems. The idea is simple, but at the same time very challenging. Urine contains nitrogen, phosphorus, potassium, and other micronutrients. If properly recovered, it could replace part of the expensive and environmentally damaging synthetic fertilizers that are currently in use. In their study, the authors tested various urine derivatives, including K-struvite, urine precipitate with CaO, electrodialysis concentrate, aurin, hydrolyzed urine, and several stabilized urine treatments. They compared these with the standard NPK fertilizer. They measured not only the biomass but also the biochemical and physiological changes within the lettuce plants. The results demonstrated that certain treatments, such as K-struvite and urine precipitate amended with CaO, achieved plant growth performance comparable to the NPK control, indicating their potential as viable and sustainable nutrient alternatives. The study reveals the potential and limits of urine derivatives, as optimization is still necessary to balance growth and stress. The general message is that urine derivatives, when processed in the right way, can close the nutrient loop, reduce reliance on the Haber-Bosch process for nitrogen production, and contribute to lowering greenhouse gas emissions from fertilizer production.

Lucchetta et al. focused on the topic of soil fertility in vineyards, where there is an issue of sustainability and dependence on mineral fertilizers. Their results revealed distinct patterns: compost (both PWC–Pruning waste compost and iPWC–inoculated (with fungal community) pruning waste compost) released nutrients more slowly and stably than mineral fertilizer inoculation. Enzymatic activities such as urease, phosphatase, and arylsulfatase increased in the soil, particularly when inoculated with compost, which suggests an improvement in nutrient cycling. Soil microbial community activity showed stronger metabolic responses under compost, especially iPWC, compared to the more basal activity under NPK. Interestingly, while compost increased microbial activity, mineral fertilizer was associated with higher Shannon diversity, likely due to carbon limitation and even distribution of species under inorganic inputs. Nevertheless, compost showed superior improvement in soil functions, highlighting its potential as a tool for vineyard sustainability. This research aligns well with circular economy principles because pruning waste, a common byproduct of vineyards, is transformed into compost, reducing reliance on chemical fertilizers and lowering the environmental footprint. Compost inoculation benefits the soil-plant system by not interfering with its microbial dynamics to a great extent. Compost inoculation also helps ameliorate nutrient deficiencies and increase soil organic content. In contrast, chemical fertilizers and certain microbial biofertilizers can have long-term impacts—the former by reducing microbial activity and the latter by interfering with existing microbial community dynamics.

Bioprocess innovations for food and soil systems

Cacace et al. investigated controlling root-knot nematodes (*Meloidogyne incognita*), among the most damaging pests in tomato production. The authors used wasted bread, brewers' spent grain, and spent coffee grounds either directly or after bioprocessing with enzymes, lactic acid bacteria, or compost tea. Their results show that all the residues, whether native or bioprocessed, significantly reduced nematode multiplication and root galling compared to untreated control soils. The most striking effect came from bioprocessed brewers' spent grain, which achieved suppression levels very close to those of the commercial nematicide used as a reference. Wasted bread also suppressed nematodes, but its effect on plant growth was not as strong as that of brewers' spent grain. This work highlights the dual functionality of food residues as soil amendments, providing nutrients while suppressing soil-borne pests. This concept is directly linked to the idea of a circular economy, as the by-products of the baking, brewing, and coffee industries, which are otherwise difficult to dispose of, can be converted into resources for crop protection, highlighting their untapped potential.

Leema et al. conducted a study on the biofortification of oyster mushrooms (*Pleurotus djamor* and *P. florida*) with zinc oxide nanoparticles (ZnONPs). The study's academic significance lies in its potential contribution to the field of mycology. The authors aimed to investigate whether the addition of ZnONPs to the substrate at the spawning stage could enhance the growth, biochemical quality, and nutrient content of these mushroom species. The results showed improved growth and yield compared to the control, with the 20 ppm treatment showing the most promising results in stimulating mycelial radial growth and final yield. Higher concentrations (40 ppm) were found to enhance biochemical properties such as phenolic and flavonoid content, along with antioxidant activity, suggesting a potential dose-dependent effect. Enzymatic assays indicated that ZnONPs triggered antioxidant responses, potentially by activating oxidative stress defense systems. Macronutrients (N, P, K, and S) and micronutrients (Zn, Fe, Mn, and Cu) also increased in the fruiting bodies, indicating that nanoparticle supplementation can significantly enhance the nutritional value of mushrooms and potentially contribute to the field of mycology.

Reviews on system-level strategies

Santos et al. reviewed cocoa by-products with a multidimensional lens, combining bibliometric and patent analyses to evaluate the scientific and technological outlook of these residues. The authors showed that the majority of the scientific output to date has focused on the agricultural and biological sciences, often assessing the nutritional and bioactive potential. Meanwhile, patents have concentrated on food ingredients, functional foods, and beverages. The review highlights the potential for value-added applications of cocoa by-products, inspiring us to explore the possibilities beyond animal feed and low-value composting.

Aragón-Guzmán et al. reviewed how small-scale coffee producers in Oaxaca can access the specialty coffee market. The authors analyzed 38 publications to determine how quality is influenced by altitude, temperature, soil, and genetic factors. The review also delved into the complexities of coffee production, highlighting the crucial role of farming practices and post-harvest methods. Socioeconomic barriers, such as limited financial resources, weak market access, and a lack of organization, were found to restrict smallholders from fully benefiting. The review concludes that collective models and community-based enterprises could offer more sustainable pathways for development.

Ravanal et al. examined sustainability, recycling, and circular economy themes that have been addressed in the global beer industry from 1972 to 2022. This is a bibliometric study that included the analysis of 417 publications. The authors observed that, while technical research on fermentation, yeast, and brewing dominates, the explicit focus on sustainability is very much limited. The study highlighted the growing role of brewers' spent grain (bagasse) as a key by-product, a beacon of hope with potential for valorization through energy recovery, bioprocessing, and applications in the food and pharmaceutical sectors. It revealed active regional collaborations, between Europe and the Americas, which focused on sustainable brewing practices, waste minimization, and by-product utilization by highlighting cross-regional knowledge exchange to accelerate the adoption of circular economy principles within the global beer industry.

Emerging insights and conclusions

Experimental studies contained in this Research Topic by Nicastro et al. and Lucchetta et al. demonstrate the feasibility of recovering nutrients from human urine and vineyard residues, which can supplement mineral fertilizers, close nutrient loops, and consequently support soil health. Bioprocess innovations, including the publications by Cacace et al. on suppressing soil-borne nematodes with food residues, and the work by Leema et al. on nanoparticle-enriched mushrooms, show how residues can be reimagined as resources for crop protection and nutritional enhancement. Other works extend the perspective to the system level, demonstrating the promise, challenges, and limitations of this approach. Overall, these studies emphasize that biovalorization and the circular bioeconomy are not abstract ideas but emerging practices, although they are still unevenly distributed.

Across these studies, one thing is evident. Waste streams from different scenarios are being pulled back into production either through human-derived fertilizers or composted residues, ultimately closing nutrient loops. Future work must push technological boundaries and focus on developing advanced methods for lignin depolymerization and addressing the complexity of diverse residues. Additionally, beyond laboratory studies, the focus should be on shaping cross-sectoral policies that integrate agriculture, energy, and waste streams. Furthermore, the social dimension cannot be ignored either. Therefore, robust life-cycle and systems assessments are equally needed to weigh true environmental gains against hidden trade-offs. Overall, this Research Topic emphasizes that research and practice at the intersection of food sustainability, waste valorization, and circular

bioeconomy are gaining momentum. The variety of studies, ranging from vineyards and mushrooms to coffee, cocoa, and beer, demonstrates that existing challenges can be multifaceted and complex. However, the solutions are equally diverse and adaptable, offering inspiration for the potential of circular farming. If implemented appropriately, these solutions could pave the way for a sustainable future. The collective insights from this Research Topic are essential for researchers working in the area of food system sustainability, as they explore sustainable solutions across various industries.

Author contributions

SS: Writing – original draft, Conceptualization, Writing – review & editing. DJ: Writing – review & editing. RM: Writing – review & editing. JV: Writing – review & editing. RS: Writing – review & editing.

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