frontiers | Frontiers in Sustainable Food Systems

TYPE Editorial
PUBLISHED 29 August 2025
DOI 10.3389/fsufs.2025.1680778

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OPEN ACCESS

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RECEIVED 06 August 2025
ACCEPTED 15 August 2025
PUBLISHED 29 August 2025

CITATION
Hasan M, Maheshwari C and Rudra SG (2025) Editorial: Agri-food waste utilization for sustainable future: challenges and opportunities.
*Front. Sustain. Food Syst.* 9:1680778.
doi: 10.3389/fsufs.2025.1680778

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# Editorial: Agri-food waste utilization for sustainable future: challenges and opportunities

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KEYWORDS

**agri-food waste, bio-waste valorization, sustainable agriculture, circular economy, upcycling**

Editorial on the Research Topic
Agri-food waste utilization for sustainable future: challenges and opportunities

The global agri-food system generates substantial volumes of waste annually, 150 billion metric tons, an amount projected to grow by 7.5 % each year, including crop residues, food processing by-products, and consumer discards. These wastes, if unmanaged, contribute to environmental harm and loss of valuable nutrients. The Research Topic "*Agri-food waste utilization for sustainable future: challenges and opportunities*" compiles interdisciplinary research aimed at transforming agri-waste/by-products, into valuable resources through valorization, lifecycle assessments, economic analyses, and policy frameworks—paving the way for circular and sustainable food systems.

Several studies under this theme highlight innovative uses of agricultural wastes in diverse sectors. Uddin et al. report the successful use of polyphenol oxidase (PPO) enzymes from fruit and vegetable peels in biodegrading and decolorizing industrial azo dyes. PPO extracted from *Solanum tuberosum* achieved an 83.29% decolorization efficiency against Reactive Black-5, revealing the potential of agro-waste-derived enzymes in eco-friendly wastewater management. Arable crops processing generates lots of waste streams like stale bread, other wastes from bread industry, legumes like soybean processing into tofu, protein isolates generates most notably soybean dregs (okara) and soybean whey which have huge potential for upscaling. In this track, Hafyan et al. review the potential of bread waste (BW) as a feedstock for producing valuable biochemicals. Unlike lignocellulosic biomass, demanding harsh pre-treatment and cumbersome decomposition reactions, BW characterized by its starchy composition and cost-effectiveness is readily accessible and has immense potential as sustainable feedstock for bioenergy and high-value biochemicals. Despite its promise in a circular bioeconomy, challenges remain, including low technological readiness, cost-effectiveness, and public acceptance. The review stresses the need for integrated sustainability assessments to scale BW-based biorefineries, provides sustainability assessment, through life cycle anslysis, technoeconomic feasibility, social lifecycle and draws out current challenges and concludes with chalking a future strategic approach for BW utilization. Similarly, Shen et al. explore the use of screw extrusion as a scalable method for treating underutilized soybean by-products.

Considering the consequences of residual metal ions, bitter flavour protein inhibitor residues and microbial contamination in soybean whey, they propose extraction of isoflavones from soy whey. They advocate the use of extrusion technology to leverage thermal and mechanical means to convert nutrient-rich soy dregs into value-added products, addressing contamination concerns and reducing environmental impacts. They conclude with enlisting the advantages, limitations, and further scope of extrusion technology for soybean by-product processing.

Besides food and agricultural waste, increased urbanization and industrialization globally has resulted into a sudden increase in wastewater production. Ghanbari et al. emphasize the reuse of wastewater and biosolids in agriculture to reap social and economic benefits and promote the sustainability of agriculture and the environment. They employed MAXQDA to organize and code the collected data from scientific articles and expert interviews, conduct systematic analysis of the components affecting sustainable management of wastewater use in agriculture. A comprehensive framework for the sustainable management of wastewater in agriculture has been provided with IQCA method wherein they have identified six key components—economic, environmental, contextual, individual, management and planning, and education and extension—that are critical for successful reuse of purified waste water. Emphasizing education and stakeholder engagement, the study provides a practical guide for developing inclusive, sustainable water strategies.

Apart from agriculture, waste from households also account for considerable environmental load. In Japan alone, 2.44 million tons (almost half of the total food waste) came from households (Morais and Ishida). Theory of Consumption Values (TCV) was applied to understand household composting behavior among Japanese households (Morais and Ishida). Use of categorical PLS-SEM approach identified key motivators like social approval, knowledge, convenience, and interest in gardening. Functional value, such as ease of use, played a central role, while emotional factors and demographics had minimal impact. Morais and Ikshida highlight the importance of community initiatives and educational outreach in mainstreaming household composting.

India produces ∼27 million MT onions, contributing widely to global consumption. Onions processing into various value-added products like dehydrated onion, onion paste, pre-cut onions generates large amounts of waste, in the form of outer skins, peels, and trimmings. Disposal of this waste is challenging for industries owing to strong characteristic odor of sulfur containing compounds. Gorrepati et al. assessed the nutraceutical potential of onion peels, from eight dark red varieties as a potential source of high-value secondary metabolites. These peels showed high total phenolic and anthocyanin contents, along with strong antioxidant activity. They reported that red colored variety BSR had 49 identified phenolic compounds, including nine flavanol, four flavones, and 30 anthocyanin glycosides. In contrast, white onion varieties had five flavanol and 11 anthocyanins. With anthocyanin content as high as 28 mg/100 g in some varieties, these can be well exploited for use in functional food and dietary supplement development. Similarly in Taiwan, Grouper fish aquaculture represents a significant sector for processed seafood. It also generates substantial by-products, posing challenges for waste management and environmental sustainability. Grouper bone hydrolysate (GBH), being rich in branched-chain amino acids (valine, isoleucine, and leucine) and bioactive peptides (total peptides 117 mg/mL) was found to significantly improve the endurance and reduced fatigue in mice (Kao et al.). Bioactive peptides were characterized using MALDI-TOF mass spectrophotometry. Supplementation at levels of 200–1,000 mg/day/ mouse led to increased swimming time, grip strength, and glycogen levels, besides lower levels of fatigue markers like ammonia and lactate. GBH showed potential for upcycled ingredient for sports nutrition and recovery supplements.

Enhancing natural resource efficiency and greener approaches for nutraceuticals extraction is an important paradigm for sustainability. Extraction of steroidal saponins (polyphyllin II and polyphyllin VII) from non-conventional parts of a rare or over-exploited herb for anti-cancer, anti-tumor, anti-inflammatory, and analgesic benefits was systematized by Guo et al.. They optimized the ultrasound-assisted and ethanol-based extraction of saponins from Paris polyphylla var. yunnanensis leaves using response surface methodology. The optimized conditions yielded 6.4 mg/g and 19 mg/g of the respective saponins from leaves compared to 52 mg/g from rhizomes.

Around 1 billion tons of agro-waste is generated annually, posing a severe environmental and the economic problems. Agricultural waste from crops, plantations and livestock such as straw, crop residues or bushes, pet manure is a potential source of organic material and soil nutrients. Use of such organic fertilizer in the long run can boost land productivity and mitigate land degradation. Saurabh et al. demonstrated that pre-treated rice straw can replace conventional substrates like vermiculite in microgreens cultivation. Alkali pre-treatment could improve the straw's water retention and physical structure, enabling healthy growth of crops like cabbage and amaranth. Compared to water holding capacity (WHC) of cocopeat 891% and vermiculite (389%), pre-treated rice straw had 673% WHC of their weight. Pre-treated rice straw offers intermediate WHC values, balancing moisture retention with aeration. Thus, even though vermiculite offered higher micronutrient levels, rice straw outperformed in growth parameters. This strategy can contribute to circular agriculture while reducing pollution from stubble burning. Poultry is an important agricultural activity for boosting farm income. By 2030, global egg production is projected to reach 90 million tons (Ferraz et al., 2018). Considering eggshell is about 10% of an egg's weight, approximately 7.67 million tons of egg shell waste (ESW) is generated worldwide annually. Li et al. proved that eggshell waste (ESW), when used for soil bio-solarization (SBS), improves soil pH, enhances microbial activity, and promoted the emission of functional volatile organic compounds linked to pest suppression, without contributing to GHG effects. ESW's ability to enrich beneficial soil bacteria with minimal phytotoxicity support its potential as a sustainable soil amendment. Futher, in simulated SBS studies, ESW could in completely inhibit germination of the hardy weed *Bidens pilosa's seeds.* Field-scale studies have been recommended to validate these findings. Wang et al. explored the use of fermented agricultural plant Jiaosu (APJ) as an eco-friendly alternative to synthetic fertilizers and pesticides. APJ as liquid fertilizer, pesticide, and oil enhancer

has been documented and its agroecological effect elaborated. Tedesco et al. evaluated fruit and vegetable waste (FVW) from Milan's wholesale markets, identifying it as a rich source of dietary fiber, polyphenols, and antioxidants. Seasonal variation in monthly FVW samples were characterized for their dietary fiber, insoluble and soluble dietary fiber, total phenolics, antioxidant activity. Higher fiber was observed in autumn and winter while antioxidant activity was highest in spring season. Safety issues at the original point where fruits and vegetables are discarded, are also not considered, such as the presence of heavy metals, pesticides, antibiotic residues, mycotoxins, or microbiological hazards. Thus, contingent on advanced processing and standardization authors support FVW's potential as a functional animal feed despite challenges such as high moisture content and variability.

Overall, this Research Topic compiled innovative uses of agri-food waste for environmental, nutritional, and economic benefits. From wastewater treatment to functional foods and sustainable agriculture, diverse strategies demonstrate huge potential for circular bioeconomy. Technologies such as screw extrusion, ultrasound-assisted extraction, and microbial fermentation are central to this transformation, enabling the production of functional foods, dietary supplements, biopesticides, and soil amendment agents from organic waste. Equally important are the social and behavioral components of waste management. As shown in studies on composting and wastewater reuse, public awareness, education, and policy support are essential to scale up sustainable practices. Tools such as the Theory of Consumption Values (TCV) and comprehensive stakeholder frameworks can guide effective community engagement and policy formulation. From an environmental perspective, repurposing waste materials such as onion peels, soybean residues, bread waste, and eggshells not only mitigate pollution but also contributes to food and nutritional security, soil health, and the availability of clean water. These innovations align with the Sustainable Development Goals (SDGs), particularly those related to responsible production, climate action, and zero hunger. Despite compositional variability, scalability and adoption challenges, integrated approaches can transform waste into valuable resources, supporting sustainability and reducing environmental impact across sectors.

Bridging these gaps will require coordinated efforts from researchers, policymakers, industries, and communities. A systems-level approach that integrates scientific innovation with economic incentives and behavioral change is critical to unlocking the full potential of agri-food waste utilization.

In conclusion, the articles in this Research Topic underscore the urgent need to reconceptualize waste as a resource. By adopting circular economy principles, leveraging innovative technologies, and fostering inclusive policies, agri-food waste can be transformed from an environmental liability into an economic asset. These multidisciplinary insights offer a practical and visionary roadmap for building a more sustainable, resilient, and resource-efficient future.

## Author contributions

MH: Writing – original draft, Writing – review & editing. CM: Writing – original draft, Writing – review & editing. SR: Writing – original draft, Writing – review & editing.

## Conflict of interest

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