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EDITORIAL

Potential of Food By-Products

Editorial: From What Is Left Behind to What Comes Next: Rethinking Food By-Products as Functional Resources

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ABSTRACT

Background: Food-processing by-products are increasingly regarded as heterogeneous biological resources rather than uniform waste streams. Their valorization potential depends not only on intrinsic composition but also on processing history, stability, safety, technofunctionality, and compatibility with realistic industrial production systems.

Scope: This editorial introduces the Special Issue "*Potential of Food By-Products: Biofunctional Compounds and Valorization Strategies*" and synthesizes eight contributions covering direct food incorporation, fraction-specific characterization, pectin recovery, advanced analytical characterization, structured plant-protein systems, optimized botanical formulations, and the translation of academic discoveries into commercial start-up ventures.

Key Themes: A unifying and consistent message emerges across these contributions: demonstrating that a food-processing residue contains valuable bioactive compounds represents only the initial step. Meaningful valorization requires matching the raw material to an appropriate functional role and rigorously validating its performance within the target food or industrial application.

Future directions: Future research should more explicitly integrate raw-material variability, processing parameters, technofunctionality, toxicological and microbiological safety, environmental life-cycle performance, process scale-up, and regulatory or market constraints—moving beyond simple extraction yield and preliminary *in vitro* bioactivity as standalone evaluative endpoints.

Conclusions: There is no single universal route from agro-industrial by-product to value-added resource. The most relevant valorization pathways are those in which biofunctional value withstands processing and translated into applications that are, safe, functional, and commercially feasible.

Keywords: Food-Processing By-Products; Valorization; Functional Ingredients; Circular Bioeconomy; Green Processing; Food Systems.

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1 INTRODUCTION

Food processing invariably leaves something behind. When wheat is transformed into flour, oranges into juice, olives into oil, or fish into commercially viable food products, a portion of the original biological material necessarily remains outside the final product. These residual fractions have historically been treated as waste, repurposed as animal feed of limited economic value, or exploited as energy substrates. Yet they retain, to varying degrees, a part of the chemistry, structure, and biological functionality intrinsic to the raw materials from which they originated. Food by-products are therefore not merely what remains following processing; rather, they constitute process-shaped biological resources whose potential value is contingent upon on how they are conceptualized and subsequently utilized.

This distinction carries considerable scientific and practical significance, since the field has advanced well beyond the preliminary question of whether food by-products contain exploitable compounds — in several cases, this question has already been conclusively answered. The more demanding and consequential challenge is whether these compounds, fractions, or intact materials can retain or acquire meaningful functional properties following industrial processing, and whether such functionality can be reliably translated into technically feasible, commercially viable, and regulatory-compliant products or processes. The contributions assembled in this Special Issue explore multiple stages of this transition, from the systematic characterization of what processing leaves behind to the rigorous investigation of what those by-products may become.

2 KEY THEMES IN THIS SPECIAL ISSUE

One overarching theme running through this collection is that the valorization potential of a by-product cannot be

dissociated from the identity of the material itself. Mumcu and Deliboran (2025) illustrate this principle with olive stones—a lignocellulosic residue traditionally and almost exclusively associated with energy recovery—which additionally contain appreciable quantities of dietary fiber, lipids, proteins, and phenolic compounds. The same material may therefore be considered a candidate for food and feed applications, activated carbon production, biosorbent fabrication, or a range of further industrial applications. Disseka *et al.* (2025) reach a related conclusion from a distinct starting point of departure: the peels, seeds, and pulp membranes generated during sweet orange processing do not behave as a single, homogeneous waste stream. Their divergent nutritional and phytochemical profiles indicate distinct functional destinations. Valorization may therefore be initiated by a seemingly straightforward, yet consequential decision: identifying which fraction is most appropriately matched to which function.

A second theme concerns the critical transition from compositional characterization to the demonstration of actual functional performance. Debbabi *et al.* (2025) reintegrated wheat bran directly into the food supply by incorporating it into *Nwasser,* a traditional Tunisian pasta preparation. In this instance, valorization was assessed not exclusively on the basis of enhanced fiber or mineral content, but equally on cooking quality, antioxidant activity, glycemic response, and consumer acceptance—thereby acknowledging the multidimensional nature of functional food validation. Ngani *et al.* (2026), in their review of natural pectin, expose a related challenge from the extraction perspective: a high pectin yield is certainly desirable, but does not in itself guarantee that the recovered polymer possesses the molecular architecture or rheological characteristics required for a specific food system. The relevant question thus progressively shifts from "How much material can be recovered?" to the more demanding and practically relevant inquiry: "What functional role can the recovered material reliably fulfil?"

Analytical science constitutes the indispensable bridge between these stages of the valorization pathway. Ridouh (2025) reviews the spectroscopic and chemical approaches employed to characterize functional biomolecules recovered from food by-products, demonstrating that rapid spectroscopic methods can effectively support screening and quality control, while chromatographic techniques remain irreplaceable when accurate molecular identification and quantification are required. The complementary application of these techniques also highlights a broader challenge within the field: increasingly sophisticated instrumentation will yield limited translational value if sample preparation protocols, calibration procedures, extraction methodologies, and reporting standards remain insufficiently standardized and harmonized cross research groups and institutions.

This Special Issue further demonstrates that valorization is not restricted to the recovery of isolated bioactive compounds; it may additionally involve the engineering of novel functional structures from recovered biological materials. Taktak *et al.* (2025) employed European eel protein isolate to produce acid-induced emulsion gels incorporating eel oil, thereby establishing a coherent connection between resource recovery, protein gelation behavior, lipid encapsulation and delivery, and microstructural organization. Takka *et al.* (2025) approached formulation from a complementary direction, employing a D-optimal mixture design to combine pomegranate bark and walnut husk with clove. Their study illustrates how value may emerge from the deliberate combination of matrices, rather than from the independent consideration of each ingredient in isolation, while additionally emphasizing the necessity of validating biological relevance through cellular or simulated digestion models that extend beyond preliminary chemical antioxidant assays.

Finally, scientific feasibility constitutes only one component of the broader and more complex valorization pathway. Saci and Gharbi (2025) examine the role of academic projects and start-up initiatives in agri-food by-product valorization within the Algerian context, directing attention to market intelligence, industrial collaboration, regulatory compliance, and pilot-scale validation requirements. These considerations become decisive determinants of success once a laboratory-scale concept is expected to operate beyond the laboratory setting. A technically effective valorization route may nonetheless prove economically or operationally unsuitable if the raw material is highly seasonal, difficult to collect, unstable during storage, or prohibitively costly to process under conditions that maintain its functional integrity.

3 Future Directions in Food By-Product Valorization

Considered together, the contributions in this Special Issue characterize valorization not as a single discrete technology but as a structured sequence of interconnected and interdependent decisions. A residue must first be rigorously understood, with attention to its composition, variability, and processing history. The material must subsequently be directed toward an appropriate valorization route, whether direct incorporation into food matrices, selective fractionation, targeted extraction, or deliberate structural transformation. Its functionality must subsequently be convincingly demonstrated in relation to a defined application, following which considerations of safety, stability, sensory quality, scale-up feasibility, economic viability, and regulatory compliance may assume equal or greater importance.

This sequential framework also reveals where the field has a persistent tendency to stop prematurely. Compositional richness, extraction yield, and *in vitro* antioxidant activity constitute valuable starting points, particularly for underexplored raw materials, but do not in themselves constitute sufficient evidence of successful valorization. A concentrated extract may require excessive solvent, water, or thermal energy; a bioactive fraction may lose functionality during food processing or storage; a nutritionally attractive powder may compromise the texture or sensory quality upon incorporation into food system. Conversely, a comparatively simple material may prove highly relevant precisely because it requires limited processing while delivering a clear technological or nutritional function.

Future work should therefore strengthen the conceptual and methodological connections between raw material characteristics, processing conditions, and final application. Extraction studies must connect operating parameters to the molecular architecture and functional properties of the recovered fraction. Biological activity should, where relevant, be complemented by assessment of bioaccessibility, bioavailability, safety, and *in vivo* efficacy. Food applications must be evaluated under realistic industrial processing and storage conditions, incorporating consumer acceptance and sensory evaluation where contextually appropriate. Environmental claims must equally account for water and energy consumption, solvent utilization, generation of secondary by-products, and scale-up considerations, rather than assuming that any form of material reutilization alone is synonymous with sustainability.

4 Conclusions

Food by-products do not constitute a uniform category of waste awaiting a universal technological solution; rather, they represent a heterogeneous ensemble of biological resources with distinct processing histories, compositional profiles, functional attributes, and potential valorization destinations. The contributions assembled in this Special Issue capture different stages along the pathway from residue characterization to functional application, and their scientific and methodological diversity is precisely what defines and reflects the current state of this research field. Future progress will depend increasingly on determining not only what can be recovered from a given by-product stream, but what should be recovered, how it should be processed to preserve or enhance its relevant functionality, and where that functionality can realistically matter. In this sense, the future of food by-product valorization lies not in further demonstrating that residual materials contain value than in learning how to preserve, transform, and situate that value where it can be meaningfully applied (Merino *et al.,* 2026).

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