CircBioCityWaste: Transformative Biorefining for Concurrent Biostimulant and Protein Recovery from Sludge and Digestates

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Keywords: Humic substances, Humic acids, Fulvic acids, Green chemistry extractions, Anaerobic digestate

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The escalating adoption of anaerobic digesters (AD) is evident within the European Union (EU) and on a global scale, positioning AD as a preeminent solution for sustainable and environmentally friendly renewable energy production and waste management. While AD effectively addresses the challenges associated with biowaste handling, it concurrently generates significant quantities of digestate as a by-product, proportionate to the input feedstock. The composition of digestates predominantly comprises residual/undigested organics, indigestible material, and a mixture of live and dead microbial biomass. Presently, the conventional practice involves the dispersal of digestate onto agricultural land; however, this method is not without inherent drawbacks. Challenges such as residual fermentation and methane emissions, potential imbalances in soil microbiome, and the risk of mineral and/or heavy metal overloading are associated with this approach. Compounding these issues are the limitations posed by restricted storage, land availability and the logistical complexities of long-haul transportation, thereby intensifying the challenges faced in the utilization of AD-generated digestates.

Policy frameworks and best practices have been directed towards upcycling digestate as a valuable feedstock for diverse applications such as waste-to-energy systems, composting, mineral and material recovery. Notably, the solubilization of proteins from this digestate-derived feedstock offers a promising avenue for waste-to-resource conversion. Conversely, the exploration of humified organic matter within anaerobic digestate (AD) by-products remains an area of insufficient research, unveiling untapped prospects for the extraction of humic substances (HS). The composition of HS encompasses humic and fulvic acids, along with insoluble humin. The well-documented beneficial and biostimulating effects of HS on plants have been recognized since the late 1900s. While conventional alkaline extraction methods exhibit limitations in terms of recovery efficiency, alternative approaches such as ultrasound, microwave, and hydrothermal extractions have been investigated in this study to assess their potential for achieving high-efficiency co-recovery of humic substances and protein.

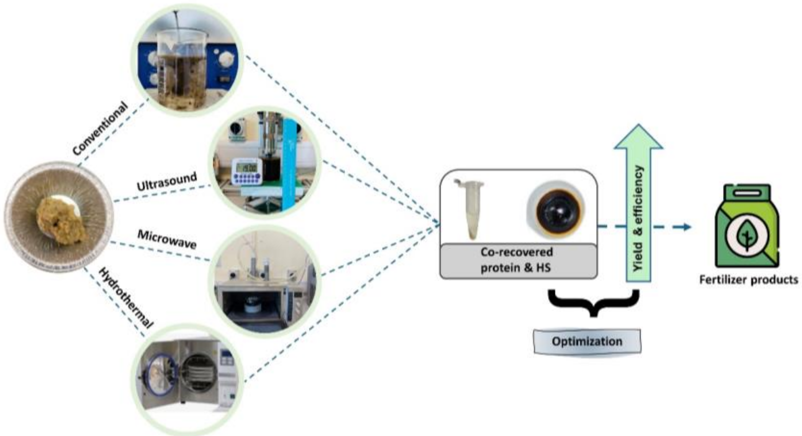

Figure 1. Graphical abstract for co recovery of protein and humic substances from sludge/digestates

Promising findings (Table 1) characterised by significant improvements in yield recovery and extraction efficiency have been attained through the implementation of novel green chemistry extraction techniques. The viability of utilizing industrial and sewage sludge digestates for the production of protein and humic-based biostimulants will be explored in alignment with the parameters set forth by the new EU Fertilizer Product Regulation (EU 2019/1009). This investigation, in its entirety, contributes valuable insights into the valorisation of digestates as fertilizer products through a cascading biorefinery approach. Emphasizing zero-waste solutions and adherence to circular bioeconomy principles, this research underscores the potential for sustainable and resource-efficient practices in the utilization of digestates.

Table 1. Humic substances yield using conventional alkaline extraction (CAE), Hydrothermal extraction (HTE), and Ultrasound assisted extraction (UAE) from dairy processing sludges (DPS), represented as avg ± s.d on dry matter basis (d.m.b).

Sample	**HA yield (% d.m.b)**		
	CAE	**HTE**	**UAE**
DPS2	5.83 ± 0.32	17.00 ± 1.36	20.23 ± 0.57
DPS3	8.99 ± 0.89	9.01 ± 0.04	38.37 ± 1.58
	FA yield (% d.m.b)		
DPS2	52.32 ± 0.63	48.64 ± 1.32	52.85 ± 1.70
DPS3	39.03 ± 0.50	56.98 ± 0.79	41.99 ± 1.09

HA: Humic acid; FA: Fulvic acid; Dairy processing sludge (DPS)

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