Biostimulatory potential of waste whey-derived fertilizer: composition, processing, and plant response

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Keywords: dairy waste, whey, fertilizers, acidic hydrolysis
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Increasing food demand requires novel fertilizer substrates that efficiently deliver essential nutrients while minimizing environmental impact. Today, environmental protection and the impact of substances on soil quality are of increasing importance. The valorization of agricultural waste aligns with sustainable farming goals by reducing emissions and preserving natural nutrient cycles. This study focused on dairy industry waste, particularly whey, as a substrate for fertilizer production. Dairy by-products such as whey can be converted into organic-mineral fertilizers, offering a renewable alternative to synthetic formulations.

The dairy industry produces large volumes of dairy products, which involves the generation of significant amounts of waste. Globally, it is estimated that the volume of dairy wastewater produced is three times that of the milk produced, ranging from 3 to as much as 11 million m^3 per year (Chaudhary et al., 2023). It contains residual milk fractions and processing by-products unsuitable for consumption. One of the main byproducts of the dairy industry is whey, which is in the form of a yellow-green, semitransparent fraction of milk that arises after the cheese-making process. Its composition can vary due to the type of cheese made, the time of year and the origin of the milk. In addition to its nutritional value as a protein source (Ahmad et al., 2019), whey is generated globally at approximately 160 million tons annually (Sharma et al., 2018). Whey-based dairy waste contains key macronutrients (N, P, K) and micronutrients (Fe, Zn) relevant to plant growth (Durpekova et al., 2022). Their processing into fertilizers can improve soil properties, and their high content of organic matter has a beneficial effect on yield growth and crop quality (Durpekova et al., 2022). The management of waste whey as an organic-mineral fertilizer for plants is one way to effectively use waste from the dairy industry. Under European Regulation 2019/1009, the raw material processing must meet specified nutrient contents for organic-mineral fertilizers and strictly address contaminants hazardous to health, since this regulation defines maximum levels of toxic elements (e.g., Cd, Pb) to ensure fertilizer safety and legal conformity within the EU market. Innovative waste processing technologies focus on obtaining a fertilizer product in the right form, improving physical properties, hygienizing the raw material and stabilizing dairy waste with sulfuric acid(VI).

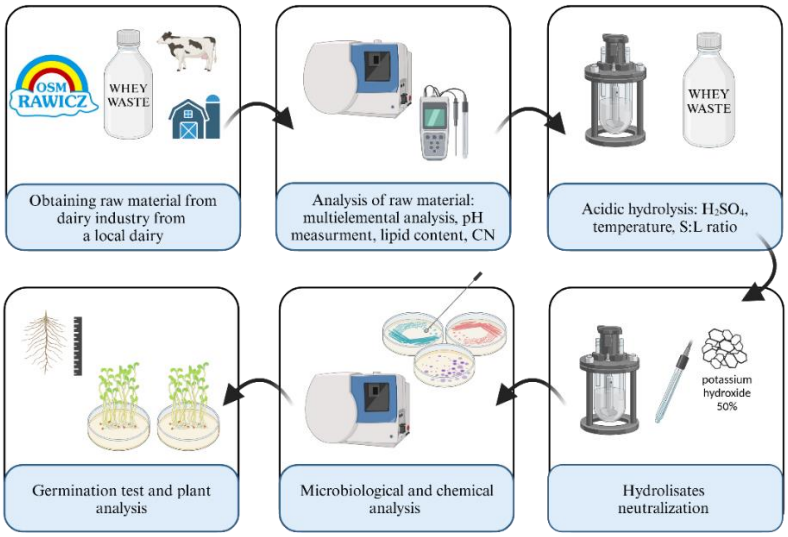

Figure. 1. Schematic of the process of converting waste whey

Figure 1 illustrates the process flow for converting waste whey into fertilizer. The study aimed to improve nutrient availability in whey-based fertilizers through acid hydrolysis with sulfuric acid(VI). Prior to hydrolysis, the raw material underwent ICP-OES multi-element analysis, nitrogen and carbon quantification (thermal conductivity detection), and chromium ion speciation assessment. The macronutrient and micronutrient composition of whey waste is presented in Table 1. Carbon ($2.77 \pm 0.415\%$) and nitrogen ($0.449 \pm 0.067\%$) were

the dominant macronutrients. Phosphorus and potassium, determined as oxides (P_2O_5 and K_2O), were present at approximately 0.1%. The raw material contained significant amounts of micronutrients, with the highest value recorded for iron (Fe) 8.31±1.25 mg/kg and zinc (Zn) 5.38±0.806 mg/kg. The analysis of metals (Cd, Cr, Pb, Ni) showed that the whey contained levels below thresholds for these elements. In addition, the determination of protein, fat content of waste whey, and dry weight and pH measurement were performed (Table 2).

Table 1. Content of selected macro-, micronutrients and toxic elements in whey waste

Macroelements								**Microelements**			
N	C	P_2O_5	K_2O	CaO	MgO	Na_2O	SO_3	Cu	Fe	Mn	Zn
%								*mg/kg*			
0,449 ± 0,067	2,77 ± 0,415	0,162 ± 0,024	0,180 ± 0,027	0,248 ± 0,037	0,035 ± 0,005	0,066 ± 0,001	0,018 ± 0,003	0,703 ± 0,105	8,31 ± 1,25	1,79 ± 0,269	5,38 ± 0,806

Table 2. Analysis of raw material – whey waste

Dry mass [%]	Protein content [%]	Lipid content [%]	pH
3.3	0.183±0.013	0.483±0.256	4.10

The acid hydrolysis process was carried out using sulfuric acid(VI) to increase the bioavailability of nutrients. The process was carried out at three different temperatures of 20°C, 50°C and 100°C with a volume ratio of acid to raw material of 1%. Neutralization was carried out with a 50% solution of potassium hydroxide until pH 5.0 was reached; subsequently, the neutralizates underwent thorough chemical multi-element analysis. Microbiological analysis was also carried out to determine the total content of microorganisms. In addition, the neutralizates were enriched with micronutrients (Cu(II), Mn(II), Zn(II), B(III)). Microbiological tests confirmed the absence of pathogens and acceptable total viable counts in all samples. A key step involved germination tests to evaluate the biostimulatory potential of hydrolyzed waste whey on plant development. The tests were conducted on cucumber (Cornichon de Paris) plants. The control group received distilled water instead of fertilizer. Plant sprouts were measured and statistical analysis was made (Statistica 13.3 program). The results showed that the organic-mineral fertilizer based on whey improved plant growth metrics, including stem elongation and fresh biomass, likely due to the availability of nitrogen and essential micronutrients. Optimal growth parameters were observed in plants treated with hydrolysate produced at 100 °C and applied at 2–3 mL doses.

Acknowledgement

This work has been funded by the European Commission's HORIZON-JU-CBE-2023 Innovation Actions program, under grant agreement No. 10115763, LANDFEED: „Unlocking efficient bio-based fertilizers for soil sustainability from underutilized side streams".

Bibliography

Ahmad, T., Aadil, R. M., Ahmed, H., Rahman, U. ur, Soares, B. C. V., Souza, S. L. Q., Pimentel, T. C., Scudino, H., Guimarães, J. T., Esmerino, E. A., Freitas, M. Q., Almada, R. B., Vendramel, S. M. R., Silva, M. C., & Cruz, A. G. (2019). Treatment and utilization of dairy industrial waste: A review. *Trends in Food Science & Technology*, *88*, 361–372. https://doi.org/10.1016/j.tifs.2019.04.003

Chaudhary, V., Kajla, P., Verma, D., Singh, T. P., Kothakota, A., Prasath, V. A., Jeevarathinam, G., Kumar, M., Ramniwas, S., Rustagi, S., & Pandiselvam, R. (2023). Valorization of dairy wastes into wonder products by the novel use of microbial cell factories. *Trends in Food Science & Technology*, *142*, 104221. https://doi.org/10.1016/j.tifs.2023.104221

Durpekova, S., Bergerova, E. D., Hanusova, D., Dusankova, M., & Sedlarik, V. (2022). Eco-friendly whey/polysaccharide-based hydrogel with poly(lactic acid) for improvement of agricultural soil quality and plant growth. *International Journal of Biological Macromolecules*, *212*, 85–96. https://doi.org/10.1016/j.ijbiomac.2022.05.053

Sharma, D., Manzoor, M., Yadav, P., Sohal, J. S., Aseri, G. K., & Khare, N. (2018). Bio-valorization of Dairy Whey for Bioethanol by Stress-Tolerant Yeast. In *Fungi and their Role in Sustainable Development: Current Perspectives* (pp. 349–366). Springer Singapore. https://doi.org/10.1007/978-981-13-0393-7_20