Valorisation of food-industry by-products as fibre and protein sources: a short review

The sustainable valorisation of food by-products has gained significant attention in modern food processing, allowing for waste reduction and enhanced resource efficiency. These by-products, often considered waste, can be transformed into valuable resources through various technologies. After presenting the conventional methods for fibre and protein valorisation from biomass, this article will provide insights into green extraction techniques to reduce solvent and chemical consumption. Dry fractionation methods will then be highlighted as sustainable methods for biomass valorisation.

1. Chemical extraction as a conventional method for biomass valorisation

Conventional methods for extracting nutrients from biomass involve wet extraction. This technique is employed for both protein and dietary fibre extraction, using solvents to dissolve the desired compounds (Flodman *et al.*, 2012; Navaf *et al.*, 2023). Plant protein isolates are typically produced through aqueous extraction in either acidic or alkaline conditions. This process includes steps such as centrifugation, isoelectric precipitation, washing, neutralisation, and drying. Similarly, dietary fibres are usually extracted with alkaline solutions. These methods can achieve isolates with over 90% purity. However, they require significant amounts of water and chemicals, including environmentally harmful solvents, and are associated with high energy consumption during the drying stages (Schutyser *et al.*, 2015; Assatory *et al.*, 2019; Buljeta *et al.*, 2023). Additionally, the severe processing conditions, involving extreme pH levels and temperatures, can lead to the denaturation of proteins and fibres, diminishing their functionality (Flodman *et al.*, 2012).

These environmental and structural considerations highlight the need for new, efficient, and sustainable methods to valorise proteins, fibres, and other compounds from food by-products and biomass overall.

2. Green extraction techniques

a. Solvent assisted extractions

Various assisted wet extraction techniques have been developed to reduce the environmental impact of conventional wet extraction. Ultrasound-assisted extraction uses sound waves to disrupt plant material structure, increasing the release and extractability of valuable compounds (Marić *et al.*, 2018; Sert, Rohm and Struck, 2022). Similarly, microwave-assisted extraction rapidly heats the solvent using microwaves, breaking down plant cell walls and allowing for more efficient extraction of intracellular substances (Yi *et al.*, 2021; Tungchaisin, Sae-Tan and Rattanaporn, 2022). These methods offer significant benefits, including lower energy consumption, reduced solvent volumes, shorter extraction times, and higher yields (Marić *et al.*, 2018).

b. Enzymes assisted extraction (EAE)

Enzyme-assisted extraction (EAE) is another eco-friendly alternative to traditional extraction methods. In EAE, enzymes are utilised to break down cell walls and degrade polysaccharides.

Commonly employed enzymes include cellulase, hemicellulase, protease, xylanase, pectinase, proteases, and glucanase, which are effective in extracting soluble dietary fibres and proteins (Kumar *et al.*, 2021; Buljeta *et al.*, 2023). Typically, this technique is used in conjunction with solvent extraction, employing either chemical solvents or water. EAE offers the benefits of being a gentle process with reduced chemical solvent requirements. It also minimises the need for high energy consumption, prolonged extraction times, or elevated temperatures to achieve substantial yields (Akyüz and Ersus, 2021). Nonetheless, the high cost of enzymes and their relatively low extraction efficiency are notable drawbacks of this method.

c. Sub-critical water extraction (SWE)

Another alternative to conventional wet extraction using chemical solvents is sub-critical water extraction (SWE). It involves high-temperature (100°C-374°C) and high-pressure water extraction (under its critical point of 22.064 MPa). In these conditions, water's polarity decreases, allowing it to behave as an organic solvent or an acid or base catalyst (Díaz-Reinoso *et al.*, 2023). SWE has been used for multiple biowaste conversions, including hydrolysis of lignocellulose, carbohydrates, lipids, and proteins, as well as the extraction of bioactive compounds (Powell, Bowra and Cooper, 2016). However, this technique presents some drawbacks, such as high operational pressures and temperatures, initial equipment investment costs, and the risk of denaturing proteins at high temperatures.

Multiple alternatives have been described to assist or replace conventional protein and fibre extraction methods. Overall, these methods reduce solvent requirements, extraction time, and energy consumption. However, recovery and drying steps are still required for these solutions, and the removal of added water by evaporation consumes large amounts of energy.

3. Dry fractionation processes

In view of the disadvantages of wet extraction methods, solvent-free, dry fractionation processes are gaining attention in the valorisation of food by-products due to their ability to separate valuable components without the use of solvents or excessive water.

a. Air Classifier

Dry milling followed by air classification has been widely adapted as a sustainable and energy-friendly approach for the enrichment of plant proteins and/or fibres from various agro-materials, including legumes, oilseed meals, cereals, and brans (Tabtabaei *et al.*, 2023).
This technique feeds air currents into a classifier chamber. The air induces centrifugal and gravitational forces inside the chamber that separate the feed flour into fine and coarse particles differing in size and density. The coarse fraction is usually enriched in fibre and/or starch, whereas the fine fraction is enriched in proteins. This technology is commonly used for the separation of starch granules from cell wall fibres and protein bodies in starch-rich legumes (pea, lentil, chickpea, and bean) (Xing *et al.*, 2020).

Although these technologies are not yet suitable for the production of high-purity protein isolates (> 90%), they have the advantage of preserving the integrity of the compounds without denaturation, thereby producing a variety of fractions with unique functional and technical properties (Assatory *et al.*, 2019; Schlangen *et al.*, 2022). This is in line with the idea of shifting towards a functionality driven industry rather than a composition-driven (hence purity-driven) one which is predominant today (van der Goot *et al.*, 2016). It was shown that mildly refined intermediates from legumes could be replace conventional pure ingredient for selected end-products while minimizing costs and reducing energy and water use by 22% and 37%, respectively (Jonkman *et al.*, 2020).

Dry fractionation of mung bean, yellow pea, and cowpea has shown to be a successful method to obtain protein-rich ingredients with functional properties that match those necessary for incorporation in plant-based food products (Schlangen *et al.*, 2022). Micronisation technologies and air-classification pilot plants have been used to produce bran-enriched milled durum wheat fractions richer in health-promoting components(Cammerata *et al.*, 2021). Silventoinen *et al*. demonstrated techno-functional properties enhancement of rye and wheat bran protein enriched fractions (Silventoinen *et al.*, 2021). Proteins and phenolic compounds enriched flours were also produced from rapeseed and sunflower meals by dry fractionation processes (Laguna *et al.*, 2018).

b. Tribo-electric separation

Tribo-electric (TE) separation is another dry fractionation technique that exploits differences in the electrical properties of particles to achieve separation. This method involves charging particles through friction and then using an electric field to separate them based on their charge differences. More commonly used in the mineral and plastic recycling industries, it has gained more attention from researchers in the food industry over the past two decades (Yang *et al.*, 2022).

Ultra-fine milling followed by tribo-electric separation has been used for the separation of proteins and lignin from canola meal (Basset, Kedidi and Barakat, 2016). The efficiency of this technique is strongly correlated to the plant cell wall properties and the mechanical milling method. TE separation has shown efficiency even when separating very fine protein-starch powder mixtures within the same order of magnitude in size and density, which is an advantage compared to air classification (Landauer and Foerst, 2018).

Conclusions

Incorporating advanced dry fractionation and extraction technologies in the valorisation of food by-products represents a significant stride towards sustainability. While cutting-edge extraction techniques such as SWE, UAE, MAE, and EAE offer precise, high-yield isolation of valuable compounds, dry fractioning methods like air classification, and electrostatic separation provide efficient, solvent-free and energy efficient fractionation. Additionally, it preserves the techno-functional properties of components present in biomass, such as proteins and fibres. These technologies are in line with the recent reclamation to switch towards a functionality-driven agri-food system for food ingredients, rather than a component- and purity-driven one. This approach leading to intermediates with lower purity provides opportunities for more resource-efficient production in food industry.

These technologies not only reduce environmental impact but also create new economic opportunities by transforming waste into valuable resources. However, each method comes with its own set of challenges, including high initial costs, potential inefficiencies, and the need for precise control and maintenance. By carefully selecting and optimising these technologies, the food industry can move towards a more sustainable, circular economy, ensuring that every part of the food supply chain is utilised effectively and responsibly.

Sources

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