Decontaminating heavy metal water using protein from plant waste

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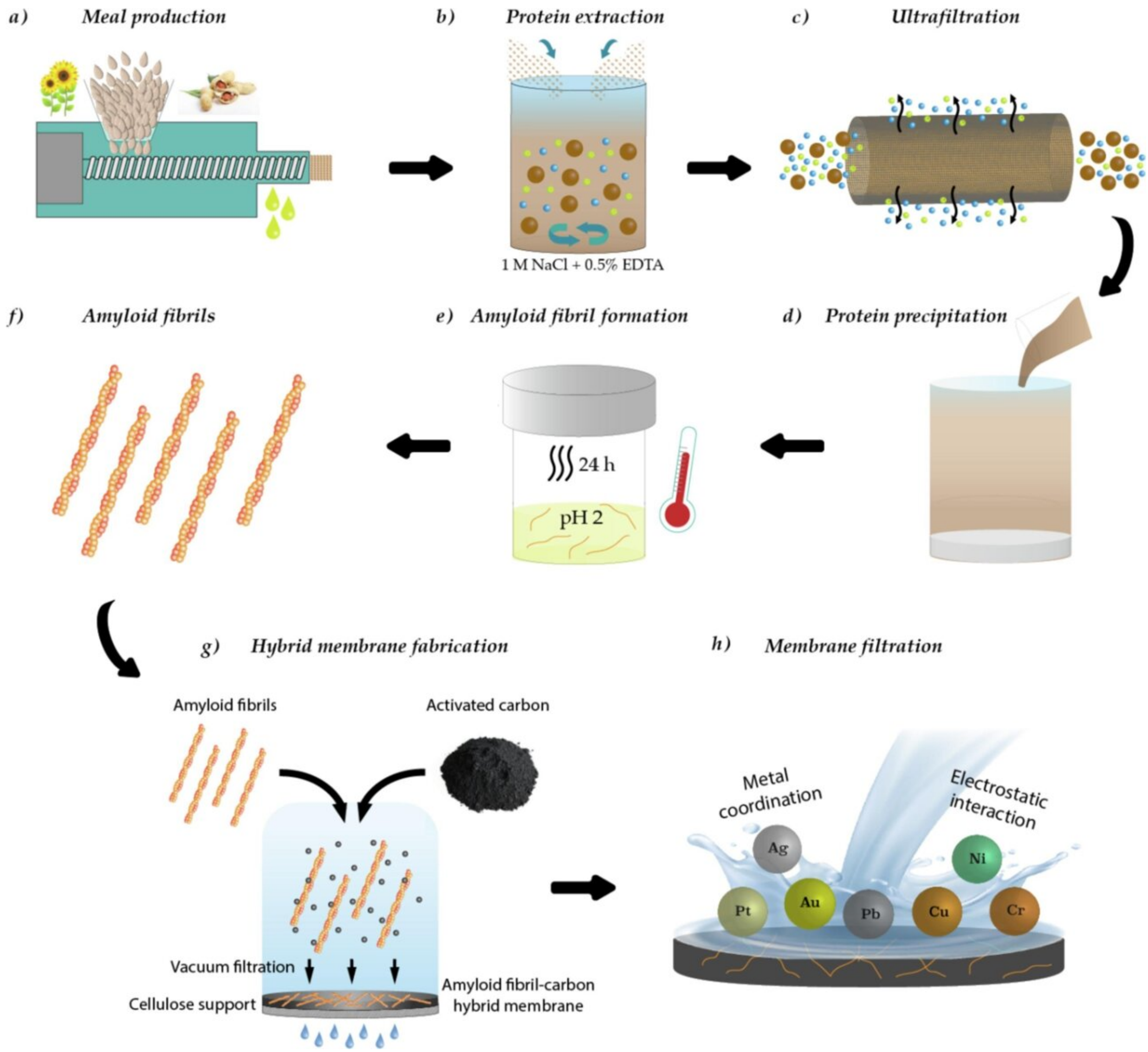

Schematic of process flow from plant seeds to the amyloid-based filtration membrane. a) Production of sunflower and peanut meals by screw-pressing seeds. b) Aqueous protein extraction of meals (brown spheres: proteins, green spheres: small molecules, blue spheres: water). c) Protein concentration with ultrafiltration. d) Protein precipitation in cold water. e) Plant protein amyloid fibril formation. f) Amyloid fibrils. g) Fabrication of amyloid-carbon hybrid membrane by filtration. h) Heavy metal filtration by plant amyloid-carbon hybrid membranes. Credit: *Chemical Engineering Journal* (2022). DOI: 10.1016/j.cej.2022.136513

Scientists from Nanyang Technological University, Singapore (NTU Singapore), in collaboration with ETH Zurich, Switzerland (ETHZ), have created a membrane made from a waste by-product of vegetable oil manufacturing that can filter out heavy metals from contaminated water.

The research team, led by Professor Ali Miserez from the School of Materials Science & Engineering and the School of Biological Sciences and NTU Visiting Professor Raffaele Mezzenga from the Department of Health Science and Technology at ETHZ, discovered that proteins derived from the by-products of peanut or sunflower oil production can attract heavy metal ions very effectively.

In tests, they showed that this process of attraction, called adsorption, was able to purify contaminated water to a degree that meets international drinking standards.

The researchers' membrane has the potential to be a cheap, low-power, sustainable, and scalable method to decontaminate heavy metals from water.

Prof. Miserez said: "Water pollution remains a major global issue in many parts of the world. Heavy metals represent a large group of water pollutants that can accumulate in the human body, causing cancer and mutagenic diseases. Current technologies to remove them are energyintensive, requiring power to operate, or are highly selective in what they filter."

"Our protein-based membranes are created through a green and sustainable process, and require little to no power to run, making them viable for use throughout the world and especially in less developed countries. Our work puts heavy metal where it belongs—as a music genre and not a pollutant in drinking water," said Prof. Miserez.

The team's research findings were published in the *Chemical Engineering Journal* in April. Their research focus in bringing about water security is aligned with the NTU 2025 strategic plan and the university's goal in mitigating humanity's impact on the environment.

Transforming vegetable oilseed meals into water filters

The production of commercial household vegetable oils generates waste by-products called oilseed meals. These are the protein-rich leftovers that remain after the oil has been extracted from the raw plant.

The NTU-led research team used the oilseed meals from two common vegetable oils, sunflower and peanut oils. After extracting the proteins from oilseed meals, the team turned them into nano-sized protein amyloid fibrils, which are rope-like structures made of tightly-wound proteins. These protein fibrils are drawn to heavy metals and act like a molecular sieve, trapping heavy metal ions as they pass by.

A kilogram of oilseed meal produces about 160g of protein.

The paper's first author, NTU Ph.D. student Mr. Soon Wei Long, said: "Protein-rich sunflower and peanut meals are low-cost raw materials, from which protein can be extracted, isolated, and self-assembled into functional amyloid fibrils for heavy metal removal. This is the first time amyloid fibrils have been obtained from sunflower and peanut proteins."

The researchers combined the extracted amyloid fibrils with activated carbon—a commonly-used filtration material—to form a hybrid membrane. They tested their membranes on three common heavy metal pollutants: platinum, chromium and lead.

As contaminated water flows through the membrane, the heavy metal ions stick onto the surface of the amyloid fibrils—a process called adsorption. The high surface-to-volume ratio of amyloid fibrils makes them efficient in adsorbing a large amount of heavy metals.

The team found that their membranes filtered up to 99.89% of heavy metals. Among the three metals tested, the filter was most effective for lead and platinum, followed by chromium.

"The filter can be used to filter any sorts of heavy metals, and also organic pollutants like PFAS (perfluoroalkyl and polyfluoroalkyl substances), which are chemicals that have been used in a wide range of consumer and industrial products," said Prof. Miserez. "The amyloid fibrils contain amino acid bonds that trap and sandwich heavy metal particles between them while letting water pass through."

The researchers say the concentration of heavy metals in contaminated water will determine how much volume of water the membrane can filter out. A hybrid membrane made with sunflower protein amyloids will require only 16kg of protein to filter the equivalent volume of an Olympic-sized swimming pool contaminated with 400 parts per billion (ppb) of lead into drinking water.

"The process is readily scalable due to its simplicity and minimal use of chemical reagents, pointing towards sustainable and low-cost water treatment technologies," said Mr. Soon. "This allows us to re-process waste streams for further applications and to fully exploit different industrial food wastes into beneficial technologies.

The trapped metals can also be extracted and further recycled. After filtration, the membrane used to trap the metals can simply be burnt, leaving behind the metals.

"While metals like lead or mercury are poisonous and can be safely disposed of, other metals, such as platinum, have valuable applications in creating electronics and other sensitive equipment," said Prof. Miserez.

"Recovering precious platinum, which costs US$33,000/kg, only requires 32 kg of protein, while recovering gold, which is worth almost US$60,000/kg, only requires 16 kg of protein. Considering that these proteins are obtained from industrial waste that is worth less than US$1/kg, there are large cost benefits."

Sustainable, low-power filtration

The paper's co-author, Prof. Raffaele Mezzenga, had previously discovered in 2016 that whey proteins derived from the milk of cows had similar metal-attracting properties.

The researchers realized that proteins from vegetable oilseed meal could also have similar properties. Their experiments showed that those proteins were not only just as effective, but also cheaper and more sustainable as it uses up waste which would otherwise be discarded or used as food for animal feedstock.

Another big advantage, the researchers say, is that this filtration requires little or no energy, unlike other methods like reverse osmosis that require electricity.

"With our membrane, gravity does most or all of the work," said Prof. Mezzenga. "This low-power filtration method can be very useful in areas where there might be limited access to electricity and power."

More information: Wei Long Soon et al, Plant-based amyloids from food waste for removal of heavy metals from contaminated water, *Chemical Engineering Journal* (2022). DOI: 10.1016/j.cej.2022.136513

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