RECENT ADVANCES IN PLANT EXTRACT DERIVED FILLERS FOR POLYMERIC MIXED MATRIX ULTRAFILTRATION MEMBRANES

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Abstract

Polymeric ultrafiltration (UF) membranes are widely used in water and wastewater treatment, but hydrophobicity, organic fouling, biofouling, and the permeability selectivity trade off continue to limit long term performance. Plant extracts and plant-derived phytochemicals offer a renewable route to engineering mixed matrix membranes (MMMs) because their phenolic, hydroxyl, carbonyl, and aromatic functionalities can modify polymer filler interactions, wettability, pore formation, and antimicrobial activity. This review summarizes recent progress in plant extract derived fillers for polymeric mixed matrix UF (MMM-UF) systems, with emphasis on studies published from 2018 to September 2026. The literature was organized into three strategies: direct incorporation of plant-derived compounds, plant extract mediated nanofillers, and extract functionalized hybrid inorganic fillers. Across representative studies, tannic acid, curcumin, green tea polyphenols, and related bioactive compounds generally reduced water contact angles and improved flux recovery, whereas hybridization with ZIF-8, MoS_2, boehmite, or metal oxides enhanced filler dispersion and multifunctionality. Selected systems achieved protein rejection of approximately 99%, flux recovery above 90%, or marked antibacterial activity. However, cross-study comparisons remain constrained by inconsistent extract composition, filler loading definitions, feed conditions, and stability tests. Future development should prioritize phytochemical standardization, strategies to prevent leaching, long term validation using real feeds, and safe scale up. Plant extract derived fillers are therefore promising building blocks for more sustainable and multifunctional UF membranes, provided that reproducibility and durability are treated as primary design criteria rather than secondary evaluations.

Keywords:
Antifouling; bio-based filler; mixed matrix membrane; polyphenol; ultafiltration

1. Introduction

Ultrafiltration is an established pressure driven separation process for removing suspended matter, colloids, macromolecules, microorganisms, and high molecular weight organic compounds from water, wastewater, and food processing streams. Polyethersulfone (PES), polysulfone (PSf), and polyvinylidene fluoride (PVDF) remain common UF polymers because of their chemical resistance, processability, and mechanical stability. Their relatively hydrophobic surfaces, however, facilitate the adsorption of proteins and natural organic matter and can accelerate microbial attachment. Fouling reduces permeate flux, increases cleaning frequency, and shortens membrane service life (Pichardo-Romero et al., 2020).

Mixed matrix membranes address these limitations by combining a continuous polymer phase with dispersed functional fillers. Conventional fillers such as metal oxides, carbon nanomaterials, zeolites, and metal organic frameworks can improve hydrophilicity, porosity, adsorption, or antimicrobial performance, but their synthesis may require harsh reagents or energy intensive processing. More importantly, poor polymer particle compatibility can produce agglomerates, interfacial voids, or blocked pores. Recent membrane research has therefore shifted toward bio-inspired and plant derived modifiers that provide reactive functional groups while reducing dependence on purely synthetic additives (Abdulkareem et al., 2026; Puri et al., 2025).

Plant extracts are chemically diverse mixtures rich in polyphenols, flavonoids, terpenoids, alkaloids, organic acids, and other secondary metabolites that can contribute functional groups for membrane modification (Nadir et al., 2020; Desiriani et al., 2023b; Raja et al., 2024). Purified or enriched plant-derived compounds such as tannic acid (TA), curcumin, and tea polyphenols have been incorporated into polymeric membranes either directly, through plant extract mediated nanoparticle synthesis, or by functionalizing inorganic and porous particles to produce hybrid fillers (Arahman et al., 2026; Chaubey et al., 2022; Mulyati et al., 2022; Sathish Kumar & Arthanareeswaran, 2019; Su et al., 2026; Zhong et al., 2024). These approaches are particularly relevant to mixed matrix membrane design because phenolic hydroxyl groups can promote hydrogen bonding and coordination interactions with polymer chains or inorganic filler surfaces, thereby improving interfacial compatibility and filler dispersion (Arahman et al., 2026; Su et al., 2026; Wang et al., 2024; Zhong et al., 2024). Such interactions can influence nonsolvent-induced phase separation (NIPS), modify membrane porosity and surface chemistry, and increase surface hydrophilicity, ultimately affecting permeability, fouling resistance, and separation performance (Desiriani, Istirokhatun, et al., 2023; Desiriani, Susanto, et al., 2023; Mulyati et al., 2022; Su et al., 2026; Wang et al., 2024).

The field is growing rapidly, yet the literature remains fragmented across direct phytochemical additives, green synthesized nanoparticles, and extract functionalized inorganic fillers. Existing reviews have largely addressed membrane biofouling mitigation, bio-inspired nanoparticles, or green functionalization strategies from a broader perspective rather than specifically examining plant extract derived fillers in polymeric mixed matrix ultrafiltration membranes (Abdulkareem et al., 2026; Pichardo-Romero et al., 2020; Puri et al., 2025). Consequently, a focused synthesis is needed to clarify how plant derived chemistry, filler incorporation routes, and polymer filler interactions collectively determine membrane performance. This review therefore evaluates recent advances in plant extract derived fillers for polymeric MMM-UF systems, emphasizing filler chemistry, incorporation routes, structure property performance relationships, antifouling and antibacterial effects, current limitations, and research priorities for scalable water and wastewater applications.

2. Materials and Methods

This article was prepared as a structured narrative review. Peer-reviewed journal literature published primarily from 2018 to September 2026 was screened using combinations of search terms including mixed matrix membrane, ultrafiltration, plant extract, plant derived, phytochemical, polyphenol, tannic acid, curcumin, green tea, green synthesized, antifouling, and antibacterial. The search covered ScienceDirect, RSC Publishing, Wiley Online Library, SpringerLink, PubMed/PMC, and Crossref indexed records. Studies were prioritized when a plant-derived compound or extract was (i) incorporated directly into a polymer matrix, (ii) used to synthesize a nanoparticle that was subsequently incorporated into or immobilized on a UF membrane, or (iii) used to functionalize an inorganic particle that was then dispersed in the polymer. Pressure-driven microfiltration or nanofiltration studies were included only when they provided directly relevant mechanistic evidence; these studies are identified as adjacent evidence rather than core UF-MMM examples. Extracted variables included polymer type, filler source and chemistry, membrane-preparation route, filler loading, water contact angle, flux or permeability, solute rejection, flux recovery ratio (FRR), antimicrobial response, and stability. Because operating pressure, feed composition, membrane area, and fouling protocols differed substantially among reports, performance values were interpreted within each study rather than ranked directly across studies.

3. Results

3.1. Main classes of plant extract derived fillers

Three recurring design routes were identified. The first is the direct incorporation of plant derived compounds into the casting solution. Examples include nano curcumin in PES, curcumin enriched surfactant nanoparticles in PSf, TA in PVDF, green tea polyphenols in PES, patchouli-oil constituents in PES, and extracted cannabinoid/terpene fractions in PES (Chaubey et al., 2022; Desiriani, Susanto, et al., 2023; Mulyati et al., 2022; Nadir et al., 2020; Sathish Kumar & Arthanareeswaran, 2019; Zainuddin et al., 2021). In these systems, the plant-derived component can function simultaneously as a hydrophilicity modifier, phase-inversion regulator, and, when bioactive, an antifouling or antibacterial agent. An earlier cellulose acetate study used *Moringa oleifera* seed extract as an antibiofouling additive for juice clarification, although its pore scale was closer to microfiltration than to UF (Wibisono et al., 2018). A related PES study combined blended and surface modified natural additives, including green tea polyphenols, and demonstrated control of organic and biological fouling using both model solutions and real surface water (Desiriani, Istirokhatun, et al., 2023).

The second route uses plant extracts as reducing, capping, or stabilizing media for nanofillers. Green synthesis can convert metal salts into nanoparticles while leaving phytochemical residues on the particle surface. Parkia speciosa-derived Ag/AgO incorporated into PSf improved water transport, humic acid separation, fouling resistance, and antibacterial performance, whereas leaf extract mediated Ag nanoparticles have also been immobilized on commercial PES UF membranes to confer antimicrobial activity (Alias et al., 2019; Gonca et al., 2021; Tiwari et al., 2023). These studies broaden the concept of a "plant-derived filler" from an organic additive to a biofunctionalized inorganic nanophase.

The third and most recent route is extract-functionalized hybrid filler engineering. TA or tea polyphenols are deposited on inorganic or porous nanostructures before being blended into the polymer. Examples include TA-functionalized oxidized MoS_2 in PES, TA-modified aluminum oxide hydroxide (boehmite) in PES, TA-metal oxide hybrids in PES, and tea polyphenol coated ZIF-8 in PES (Arahman et al., 2026; Aryanti et al., 2026; Su et al., 2026; Zhong et al., 2024). This route is attractive because the inorganic phase supplies rigidity, porosity, or adsorption sites, whereas the plant derived shell improves interfacial compatibility and surface hydration. Related natural bioadditive MMMs using gum Arabic with graphene oxide or chamomile derived particles show comparable trends in hydrophilicity and fouling control; these studies were treated as contextual evidence because the modifiers are not plant extracts in the strict sense (Chai et al., 2021; Raja et al., 2024).

Table 1. Representative plant extract derived fillers reported for polymeric UF membranes

Filler / plant-derived component	Polymer / route	Loading	Reported performance highlight	Reference
Nano-curcumin	PES; NIPS	2 wt%	PWF 64.48 L m^{-2} h^{-1}; enhanced antibiofouling activity against E. coli and P. aeruginosa	(Sathish Kumar & Arthanareeswaran, 2019)
Cannabinoids + terpenes	PES; blending/NIPS	Optimized blend	Contact angle about 40°; improved water retention, flux, and antibacterial/antibiofouling performance; no detectable leaching reported	(Nadir et al., 2020)
Patchouli oil + Pluronic	PES; blending/NIPS	Optimized blend	Hydrophilic antimicrobial UF membrane; pesticide rejection up to ~75%	(Zainuddin et al., 2021)
Tannic acid	PVDF; blending/NIPS	2 wt%	Clean water flux up to ~3.3-fold of pristine membrane; FRR ~78–83% versus ~59% for pristine	(Mulyati et al., 2022)

Filler / plant-derived component	Polymer / route	Loading	Reported performance highlight	Reference
Curcumin-NaDBS nanoparticles	PSf; blending/NIPS	5 wt%	Pure water permeability ~3.2-fold higher than pristine; FRR >90%; improved BSA rejection and antibacterial activity	(Chaubey et al., 2022)
Green-tea polyphenol + collagen	PES; blending/NIPS	3 wt% PGT + 1 wt% collagen	PWF 353.9 L m⁻² h⁻¹; CA 36.9°; solute rejection 98.5%; improved FRR and bacterial removal	(Desiriani, Susanto, et al., 2023)
TA-O-MoS_2	PES; blending/NIPS	0.1 wt%	Flux 140.98 L m^{-2} h^{-1} bar^{-1}; PEG20k rejection 91%; improved organic removal and antifouling	(Zhong et al., 2024)
Tannic acid	PVDF; blending/NIPS	Optimized TA blend	>99% Fe^{3+} removal maintained over repeated cycles; high oil removal and improved acid resistance and antifouling performance	(Wang et al., 2024)
AlOOH-TA hybrid	PES; blending/NIPS	Optimized M4	PWF 37.71 L m^{-2} h^{-1}; CA 56.7°; HA rejection 61.4%; FRR 99.72%	(Arahman et al., 2026)
TA-metal oxide hybrid	PES; blending/NIPS	1 wt% hybrid	TA–ZrO_2 gave the strongest combined water-flux, dye-removal and antifouling response among tested oxides	(Aryanti et al., 2026)
Tea polyphenol@ZIF-8	PES; blending/NIPS	0.3 g filler formulation	Permeability 638.4 L m^{-2} h^{-1} bar^{-1}; BSA rejection 99%; Congo-red rejection 96.9%; antibacterial activity	(Su et al., 2026)

Note: Values are reproduced as reported by the cited studies and should not be interpreted as a cross-study ranking because pressure, feed composition, membrane thickness, and test protocols differ. CA, water contact angle; FRR, flux recovery ratio; HA, humic acid; NIPS, nonsolvent-induced phase separation; PWF, pure-water flux; TA, tannic acid.

3.2. Structure property performance trends

Across the studies in **Table 1**, enhanced surface hydration is the most consistent mechanism linking plant-derived chemistry to UF performance. Phenolic-rich molecules contain multiple hydroxyl groups that increase affinity for water. When these groups remain accessible at the membrane water interface, the resulting hydration layer reduces the thermodynamic driving force for protein and humic substance adsorption. TA addition to PVDF, for example, increased water uptake and porosity while improving FRR (Mulyati et al., 2022). Green tea polyphenols combined with collagen similarly produced a more hydrophilic PES membrane with strong solute rejection and improved resistance to BSA and humic acid fouling (Desiriani, Susanto, et al., 2023).

Plant derived fillers also modify membrane formation. During NIPS, hydrophilic additives can accelerate solvent nonsolvent exchange and promote larger or more interconnected pores, thereby increasing clean water flux. The effect is not universally monotonic. Increasing filler concentration can also raise dope viscosity and induce particle aggregation or pore obstruction. Curcumin enriched surfactant nanoparticles illustrate this balance: progressive addition improved permeability and antifouling performance up to an optimum composition, while the filler chemistry simultaneously contributed antibacterial activity (Chaubey et al., 2022). Similar concentration dependent behavior is widely observed in bio inspired nanofiller systems (Puri et al., 2025).

Hybrid fillers provide a second level of control by separating functions between an inorganic core and a plant-derived interfacial layer. In TP@ZIF-8/PES, tea polyphenols improved compatibility between ZIF-8 and PES and suppressed particle aggregation; the optimized membrane combined high permeability with approximately 99% BSA rejection and antibacterial activity (Su et al., 2026). TA-functionalized MoS_2 and AlOOH-TA systems likewise used phenolic chemistry to enhance wettability and interfacial dispersion while retaining the adsorption or structural benefits of the inorganic phase (Arahman et al., 2026; Zhong et al., 2024). This hybrid strategy is particularly promising because it addresses a central challenge in MMM design: poor filler polymer affinity. The integrated pathway linking biomass source, extract chemistry, filler design, membrane structure, and ultrafiltration performance is summarized in **Figure 1**.

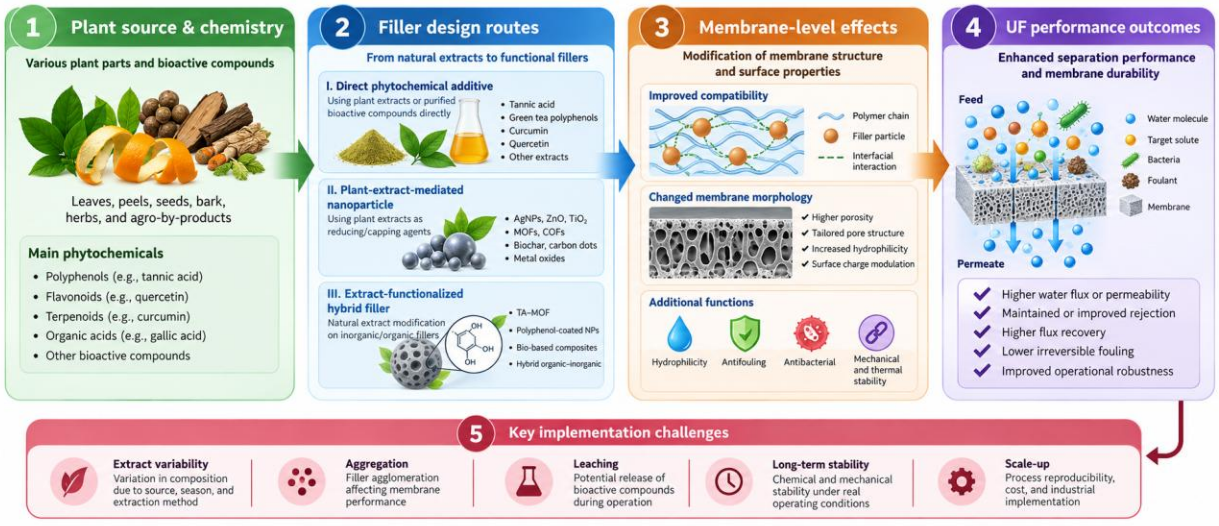

Figure 1. Conceptual pathway of plant extract derived fillers in polymeric mixed matrix ultrafiltration membranes.

3.3. Emerging design principles

A cross-study synthesis suggests five practical design principles for plant extract derived MMMs. First, phenolic and polar rich extracts can improve polymer filler interactions, membrane hydrophilicity, and fouling resistance, as reported for tannic acid, tea polyphenols, and curcumin-based systems (Desiriani, Susanto, et al., 2023; Mulyati et al., 2022; Sathish Kumar & Arthanareeswaran, 2019; Su et al., 2026; Wang et al., 2024). Second, filler loading should be optimized because excessive addition may cause agglomeration and unfavorable transport pathways (Arahman et al., 2026; Su et al., 2026; Wang et al., 2024; Zhong et al., 2024).

Third, the role of the plant extract should be clearly defined, whether as a direct additive or as a reducing, capping, stabilizing, or interfacial modifying agent for nanofillers (Arahman et al., 2026; Gonca et al., 2021; Tiwari et al., 2023). Fourth, good polymer filler compatibility is essential because plant derived molecules can improve filler dispersion and interfacial stability (Su et al., 2026; Wang et al., 2024; Zhong et al., 2024).

Fifth, membrane performance should be assessed using multiple criteria, including permeability, rejection, flux recovery, irreversible fouling, and filtration stability rather than clean-water flux alone (Arahman et al., 2026; Desiriani, Istirokhatun, et al., 2023; Desiriani, Susanto, et al., 2023; Su et al., 2026; Wang et al., 2024). This is particularly important for agricultural, food processing, and decentralized water treatment applications, where fouling resistance and operational stability strongly affect long term performance (Pichardo-Romero et al., 2020; Wibisono et al., 2018). The key reporting priorities for improving reproducibility and cross-study comparison are summarized in **Table 2**.

Table 2. Recommended reporting priorities for plant-extract-derived MMM studies

Aspect to report	Why it matters	Minimum information recommended
Extract identity and source	Extract variability is a major source of irreproducibility.	Plant species/part, extraction solvent, extraction conditions, and whether the additive is crude extract, fraction, or purified compound.
Filler design route	Mechanism differs among direct additives, green synthesized nanofillers, and hybrid fillers.	Direct blending, green synthesis, surface functionalization, or hybrid assembly, with a brief schematic description.
Polymer filler ratio	Performance usually shows an optimum loading window.	Dope composition, additive loading basis (wt% of polymer or total solids), and viscosity if available.
Membrane structure metrics	Morphology connects chemistry to performance.	Contact angle, porosity, mean pore size or MWCO, SEM images, and evidence of dispersion/aggregation.
Performance protocol	Cross study comparison is impossible without consistent testing details.	Feed composition, operating pressure, flux or permeability units, rejection calculation, fouling model, and number of cycles.
Stability and sustainability	Practical adoption depends on durability and real environmental benefit.	Leaching test, reuse/regeneration data, real water validation, and a concise discussion of solvent/energy demand.

Note: Standardized reporting would improve reproducibility and enable more meaningful comparison across studies.

4. Discussion

4.1. Antifouling and antibacterial mechanisms

The antifouling effect of plant derived fillers is predominantly physicochemical. Increased hydrophilicity promotes a tightly associated hydration layer that limits direct contact between hydrophobic foulants and the polymer surface. Surface charge and pore architecture further influence foulant transport. Consequently, FRR usually improves when the filler remains well dispersed and accessible. Examples include TA/PVDF, curcumin-NaDBS/PSf, and AlOOH-TA/PES systems, all of which showed substantially improved flux recovery relative to their respective unmodified membranes (Arahman et al., 2026; Chaubey et al., 2022; Mulyati et al., 2022). However, a highly hydrophilic membrane is not automatically nonfouling; pore enlargement, roughness, surface heterogeneity, and irreversible adsorption can counteract the benefits of hydration.

Antibacterial effects arise through more diverse mechanisms. Curcumin, tea polyphenols, terpenes, and related phytochemicals can disrupt microbial membranes, interfere with cellular proteins, or induce oxidative stress through mechanisms that depend on composition and concentration. Green synthesized Ag/AgO adds a stronger inorganic antimicrobial mechanism, while plant metabolites act as reducing and capping agents (Alias et al., 2019; Gonca et al., 2021; Tiwari et al., 2023). In direct plant derived systems, nano-curcumin/PES and green tea-containing PES membranes suppressed bacterial attachment or growth without relying exclusively on metal ions (Desiriani, Susanto, et al., 2023; Sathish Kumar & Arthanareeswaran, 2019). This distinction matters for applications in which nanoparticle release, ecotoxicity, or food contact safety is a concern.

4.2. Direct extract versus hybrid filler strategies

Direct addition is attractive because it is simple, compatible with conventional NIPS, and minimizes synthesis steps. It is therefore potentially favorable for scale up. Its main weakness is molecular mobility: low molecular weight phytochemicals may migrate during phase inversion, leach during filtration, or become buried within the polymer, where their functional groups are inaccessible. Nadir et al. (2020) specifically examined the retention of extracted cannabinoids and terpenes in PES and reported no detectable leaching under their test conditions, but such stability assessments remain uncommon in the literature.

Hybridization can reduce these limitations by anchoring phytochemicals to a larger particle before membrane fabrication. TA is particularly useful because its multiple catechol and gallol groups can coordinate metals and adsorb strongly onto many inorganic surfaces. This chemistry has enabled TA-O-MoS_2, AlOOH-TA, and TA-metal oxide fillers, while tea polyphenols have been used to coat ZIF-8 (Arahman et al., 2026; Aryanti et al., 2026; Su et al., 2026; Zhong et al., 2024). Hybrid fillers can therefore combine hydrophilicity, adsorption, antimicrobial activity, and structural reinforcement. The trade-off is greater synthetic complexity and a stronger need for particle size and dispersion control.

4.3. Evidence gaps and limitations

The largest barrier to comparing plant extract derived MMMs is insufficient standardization. "Plant extract" may refer to a crude solvent extract, an enriched polyphenol fraction, a purified compound, an essential oil, or a plant mediated nanoparticle. Composition can vary with species, cultivar, plant part, maturity, extraction solvent, temperature, and storage conditions. Yet many membrane studies report only the filler mass fraction and do not provide chromatographic fingerprints, total phenolic content, or marker compound concentrations. Without adequate chemical characterization, reproducing membrane performance across laboratories is difficult.

Performance testing is similarly heterogeneous. Water permeability may be reported either as flux at a single pressure or as pressure normalized permeability; fouling tests use different BSA or humic acid concentrations; and antibacterial assays range from inhibition zones to viable colony counts. Short laboratory runs dominate the literature, whereas long duration cross flow filtration, repeated chemical cleaning, exposure to real wastewater, and filler release analyses remain limited. Adjacent work with green synthesized Ag nanoparticles and curcumin functionalized nanofiltration membranes demonstrates the broader feasibility of plant mediated surface and nanofiller engineering, but it also reinforces the need to distinguish membrane class, pore scale, and operating conditions when transferring conclusions to UF (Bashir et al., 2025; Moradi et al., 2020).

A further consideration is sustainability itself. Plant derived does not automatically mean low impact. Extraction may consume organic solvents and energy, whereas hybrid fillers can still contain metals or nanomaterials that require end of life control. Future claims of "green" membrane design should therefore combine renewable feedstock arguments with solvent selection, material efficiency, leaching and toxicity testing, and, where feasible, life cycle or techno economic analysis.

4.4. Future perspectives

Future research should focus on reproducible structure function relationships rather than flux improvement alone. Extract chemistry, filler loading, aggregation, and interfacial stability should be controlled systematically to balance permeability, rejection, fouling resistance, and membrane integrity (Arahman et al., 2026; Su et al., 2026; Wang et al., 2024; Zhong et al., 2024). Long term filtration and repeated cleaning tests are also needed to confirm membrane stability under realistic operating conditions (Pichardo-Romero et al., 2020; Puri et al., 2025).

Agricultural and food processing residues represent promising sources of plant-derived modifiers, linking biomass valorization with membrane development (Raja et al., 2024; Wibisono et al., 2018). Future designs are likely to favor multifunctional hybrid fillers that improve polymer filler compatibility while retaining adsorptive or antimicrobial functions (Arahman et al., 2026; Su et al., 2026; Zhong et al., 2024). Validation using real water and agro-industrial or food-processing streams remains essential for practical application.

4.5. Practical implications for sustainable membrane engineering

Plant extract derived fillers are promising for low to medium pressure membrane systems because they can simultaneously improve hydrophilicity, fouling resistance, antibacterial activity, and, in some cases, pollutant removal (Arahman et al., 2026; Desiriani, Susanto, et al., 2023; Su et al., 2026; Wang et al., 2024; Zhong et al., 2024). This multifunctionality is particularly relevant to food processing and agro-industrial water treatment, where organic fouling and microbial contamination are major operational concerns (Raja et al., 2024; Wibisono et al., 2018).

Practical implementation will require simpler and more reproducible fabrication routes, controlled extract and filler preparation, and compatibility with conventional phase inversion processes. Future studies should therefore evaluate not only membrane performance but also long term stability, process simplicity, cost, and resource efficiency to support scale up (Abdulkareem et al., 2026; Pichardo-Romero et al., 2020; Puri et al., 2025).

4.6. Relevance to agricultural and food related separations

The reviewed membrane designs are particularly relevant to agricultural and food processing streams, where proteins, polysaccharides, colloids, pigments, and microorganisms can promote pore blocking, cake formation, and biofouling in UF membranes (Desiriani, Istirokhatun, et al., 2023; Pichardo-Romero et al., 2020). Plant extract derived fillers are advantageous because improved hydrophilicity and bioactive surface chemistry can reduce protein adsorption and microbial attachment (Desiriani, Susanto, et al., 2023; Raja et al., 2024). Their potential has also been demonstrated in applications such as juice clarification and wastewater treatment (Raja et al., 2024; Wibisono et al., 2018).

Agricultural and food-processing residues also offer potential sources of plant-derived compounds for membrane modification, linking biomass valorization with sustainable separation-material development (Abdulkareem et al., 2026; Puri et al., 2025). Future work should combine membrane-performance evaluation with better characterization and standardization of biological raw materials. With improved reproducibility, plant extract derived fillers could provide a promising route toward more sustainable UF membrane systems. The critical translation priorities for future studies are summarized in **Figure 2**.

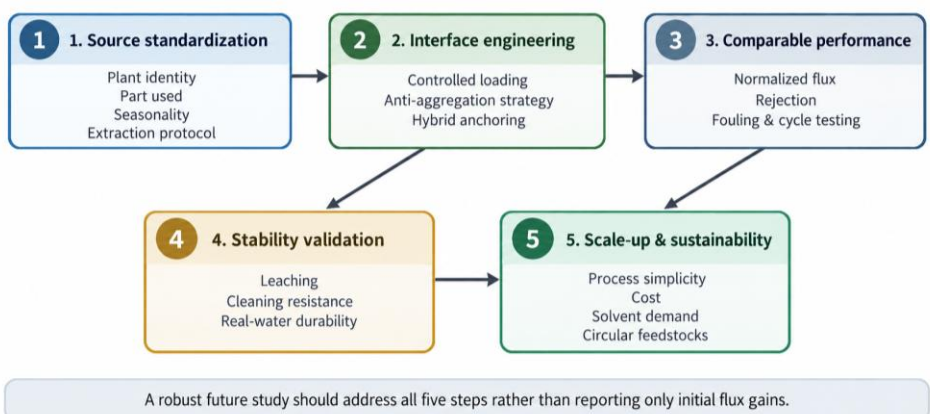

Figure 2. Roadmap for translating plant extract derived mixed matrix membranes toward practical use.

5. Conclusion

Plant extract derived fillers have evolved from simple hydrophilic additives into multifunctional components that can influence phase inversion, improve polymer filler compatibility, mitigate organic and biological fouling, and provide additional adsorption or antibacterial functions. Direct phytochemical incorporation offers simpler fabrication, whereas extract mediated and extract functionalized hybrid fillers provide greater opportunities for immobilization and multifunctionality. Tannic acid, curcumin, tea polyphenols, and plant mediated nanofillers demonstrate the potential of plant derived chemistry to improve UF membrane performance using established polymers such as PES, PSf, and PVDF. Future progress should prioritize reproducibility and practical validation, particularly through standardized extract characterization, optimized filler loading, leaching assessment, long-term fouling and cleaning tests, and evaluation with real feed streams. With these advances, plant extract derived fillers could support more sustainable polymeric mixed matrix UF membranes for water, wastewater, and agro-food separations.

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Conflict of Interest

The author delcares no conflict of interest.

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