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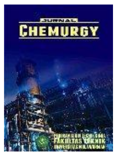

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NATURAL DEEP EUTECTIC SOLVENTS BERBASIS KOLIN KLORIDA UNTUK EKSTRAKSI SELEKTIF HESPERIDIN DARI LIMBAH KULIT JERUK: SEBUAH TINJAUAN

CHOLINE CHLORIDE BASED NATURAL DEEP EUTECTIC SOLVENTS FOR THE SELECTIVE EXTRACTION OF HESPERIDIN FROM ORANGE PEEL WASTE: A REVIEW

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Abstrak

Pengolahan sitrus industri menghasilkan volume produk sampingan yang sangat besar, termasuk kulit dan biji, yang merupakan sumber kaya flavonoid bioaktif hesperidin. Studi ini menggunakan tinjauan data sekunder yang diperoleh dari Scopus untuk mengevaluasi efektivitas pelarut *natural deep eutectic solvents* (NADES) berbasis kolin klorida untuk pemulihan hesperidin secara selektif. Hasil menunjukkan bahwa formulasi NADES tertentu dapat mengungguli pelarut organik tradisional dalam hal rendemen, sementara donor ikatan hidrogen berbasis poliol memberikan pemulihan dan stabilitas jangka panjang yang lebih unggul untuk hesperidin dibandingkan dengan alternatif asam. Performa ekstraksi dioptimalkan dengan mengelola viskositas pelarut dan perpindahan massa melalui kadar air terkontrol sebesar 20% hingga 30% (b/b) dan suhu antara 50°C hingga 80°C. Akhirnya, kemampuan daur ulang yang tinggi dan tingkat retensi yang melebihi 96% selama beberapa siklus menunjukkan kelayakan ekonomi dan lingkungan dari pelarut ramah lingkungan ini, yang mendukung transisi menuju bioekonomi sirkular yang berkelanjutan

Kata Kunci: hesperidin, *natural deep eutectic solvents* (NADES), kolin klorida, limbah kulit jeruk, ekstraksi selektif

Abstract

Industrial citrus processing generates massive volumes of by-products, including peels and seeds, which are rich sources of the bioactive flavonoid hesperidin. This study utilizes a review of Scopus-retrieved secondary data to evaluate the effectiveness of choline chloride-based natural deep eutectic solvents (NADES) for selective hesperidin recovery. Results indicate that specific NADES formulations can outperform traditional organic solvents in yield, while polyol-based hydrogen bond donors provide superior recovery and long-term stability for hesperidin compared to acidic alternatives. Extraction performance is optimized by managing solvent viscosity and mass transfer through a controlled water content of 20% to 30% (w/w) and temperatures between 50°C and 80°C. Finally, high recyclability and retention rates exceeding 96% over multiple cycles demonstrate the economic and environmental feasibility of these green solvents, supporting the transition toward a sustainable circular bioeconomy.

***Keywords**: hesperidin, natural deep eutectic solvents (NADES), choline chloride, orange peel waste, selective extraction*

1. INTRODUCTION

1.1 The Problem

Citrus fruits are among the most economically significant fruit crops globally, with an annual production exceeding 124 million tonnes. However, industrial processing and consumption generate massive volumes of by-products. During juice extraction alone, approximately 50% of the fresh fruit weight, comprising the peel, seeds, and albedo, is discarded. Currently, these by-products are disposed of in large quantities and are often not appropriately utilized. This management gap represents a significant missed opportunity, as citrus waste is a rich source of valuable bioactive compounds, including pectin, essential oils, and flavonoids such as hesperidin. Utilizing this biomass as a resource for value-added products is essential for establishing a sustainable circular bioeconomy and reducing the environmental impact of citrus processing (Garg et al., 2026).

1.2 The Molecule

Hesperidin is a member of the flavanone family of flavonoids, naturally occurring in the albedo and inner peels of citrus fruits. The molecule is structurally composed of an aglycone and the disaccharide rutinose. Known for its high antioxidant activity, hesperidin effectively scavenges free radicals and exhibits several beneficial biological properties, including anti-inflammatory, antiviral, and anticarcinogenic effects. Additionally, it contributes to vascular health by strengthening blood vessel walls and helping to prevent bruising (Abed et al., 2026).

1.3 The Gap

While deep eutectic solvents (DES) are frequently positioned as green alternatives to traditional media, their environmental and toxicological profiles are ultimately dictated by the nature of their specific constituents. A notable gap remains between the idealized green concept and actual solvent compositions, as many reported procedures still utilize systems containing toxic, persistent, or hazardous components such as substituted phenols. Simply substituting a volatile organic solvent with a DES does not automatically render an analytical procedure environmentally friendly. This discrepancy underscores the necessity for a more rigorous, safety-driven selection and design of these solvents, especially since the eventual breakdown of hydrogen bonds during disposal can release the original hazardous precursors into the environment (Krekhova et al., 2026).

1.4 The Objective

This review aims to evaluate the performance of choline chloride-based natural deep eutectic solvents (NADES) for the selective recovery of hesperidin from orange peel waste. By synthesizing literature from the Scopus database, the study analyzes the impact of hydrogen bond donor selection and optimized process parameters, specifically water content and temperature, on extraction efficiency and molecular stability. Furthermore, the review examines the economic and environmental feasibility of these solvents by assessing their recyclability and mass-driven green metrics.

2. RESEARCH METHODOLOGY

This study employs a review methodology based on secondary data retrieved from the Scopus database. Scopus was selected as the primary source due to its status as one of the largest curated databases of peer-reviewed literature, ensuring that the gathered data maintains high academic standards and scientific validity.

2.1 Search Strategy

To ensure a comprehensive data set and avoid the over-filtering trap, where overly restrictive search terms fail to capture relevant papers, the search strategy utilized both specific and broad keywords. Given that Scopus operates as a literal search engine, the search terms were expanded to include flavonoids (the chemical family) and citrus (the biological source). This approach allows for the retrieval of studies that may focus on broader citrus flavonoids but contain essential, specific data for hesperidin.

2.2 Scopus Search Strings

The following standard search string is used to ensure that 10 references are evaluated for each sub-section of the review, but only those relevant from the 10 will be discussed further:

Table 1. Search strings utilized in Scopus

Section	Target Focus	Scopus Search String
3.1.1 Comparative Yield	Organic vs. NADES	TITLE-ABS-KEY (hesperidin AND (NADES OR "deep eutectic") AND (yield OR efficiency) AND comparison)
3.1.2 Effect of HBD	Acids vs. Polyols	TITLE-ABS-KEY ("choline chloride" AND ("organic acid" OR polyol OR glycerol OR urea) AND extraction AND yield)
3.1.3 Influence	Water & Temperature	TITLE-ABS-KEY ((NADES OR "deep eutectic") AND (water OR temperature OR viscosity) AND extraction AND yield)
3.1.4 Sustainability	Recyclability	TITLE-ABS-KEY (("deep eutectic" OR NADES) AND (recycl* OR reus* OR "E-factor" OR "green chemistry"))

3. RESULT AND DISCUSSION

3.1 Result

3.1.1 Comparative Yield

Natural Deep Eutectic Solvents (NADES) have emerged as sustainable and efficient alternatives to volatile organic compounds for the recovery of bioactive substances from citrus waste (Ren et al., 2026). Traditional extraction techniques typically rely on solvents such as ethanol, methanol, or acetone, which are often constrained by environmental toxicity and varying recovery efficiencies (Zhou and Tang, 2025). Choline chloride-based NADES offer a green solution by utilizing natural components to form eutectic mixtures with strong dissolution abilities, specifically tailored for polar flavonoids like hesperidin (Wang et al., 2025).

Comparative data indicate that specific NADES formulations can surpass the extraction performance of common organic solvents. For instance, a choline chloride and diethanolamine system achieved a hesperidin extraction yield of 6.26%, which was significantly higher than the results obtained using 70% ethanol (Zhou and Tang, 2025). Similarly, systematic screenings of over 200 solvents found that optimized deep eutectic systems reached hesperidin yields exceeding 14.00 mg/g, outperforming the total flavonoid recovery levels of 70% ethanol (Ren et al., 2026). While some organic solvents like 80% ethanol show high initial yields in specific conditions, optimized NADES mixtures remain competitive and demonstrate potential for increased efficiency through temperature and molar ratio optimization (Lambangsari et al., 2025).

The enhanced extraction capacity of NADES is primarily attributed to their ability to disrupt plant cell wall structures and provide multiple hydrogen-bonding sites for target solutes (Zhou and Tang, 2025). These solvents facilitate mass transfer by balancing viscosity and polarity to match the molecular structure of hesperidin (Ren et al., 2026). Furthermore, integrating choline chloride-based solvents with advanced separation techniques like resin adsorption has been shown to increase total yield by 2.15-fold compared to traditional sequential methods (Wang et al., 2025). This adaptability makes NADES a promising medium for the selective and high-yield recovery of citrus-derived bioactive molecules (Jiang et al., 2024).

Table 2. Comparative hesperidin yields (organic vs. NADES/DES)

Solvent Type	Specific Solvent System	Reported Yield	Reference
Organic	70% Ethanol	< 6.26%	(Zhou and Tang, 2025)
NADES/DES	Choline chloride : Diethanolamine	6.26%	(Zhou and Tang, 2025)
Organic	70% Ethanol	12.03 mg/g*	(Ren et al., 2026)
NADES/DES	BTMAC-Xylitol	12.08 mg/g	(Ren et al., 2026)
Organic	80% Ethanol	27.47 mg/g	(Lambangsari et al., 2025)
NADES/DES	Choline chloride : Ethylene Glycol	17.6 mg/g	(Lambangsari et al., 2025)

**Reported as total flavonoid yield inclusive of hesperidin.*

3.1.2 Effect of HBD

The choice between organic acids and polyols as hydrogen bond donors (HBD) fundamentally alters the chemical environment and extraction performance of natural deep eutectic solvents (NADES). Organic acid-based HBDs, such as lactic and malic acid, typically result in very low pH environments, often ranging from 0.0 to 2.0 (Munir et al., 2026). This high acidity facilitates the hydrolysis of plant cell walls, which enhances the release of intracellular compounds into the solvent (Munir et al., 2026). Furthermore, acidic conditions stabilize specific polar pigments like anthocyanins by maintaining their flavilium cation form, leading to higher recovery yields (Todorović et al., 2026). In contrast, polyol-based NADES, such as those using glycerol, result in higher pH levels and may exhibit lower efficiency for highly polar phenolic acids (Munir et al., 2026). However, for specific flavonoids like hesperidin in orange peel, polyol-based systems like ChCl:Glycerol have been found to provide higher extraction yields and superior stability compared to acidic malic acid-based formulations (Munir et al., 2026).

Physical properties, particularly viscosity and mass transfer kinetics, are heavily influenced by the HBD's molecular structure. Both organic acids (e.g., malic acid) and polyols (e.g., glycerol) are characterized by high viscosity due to their dense internal hydrogen-bonding networks (Wang et al., 2026; Munir et al., 2026). The number of available hydroxyl groups in a polyol directly correlates with solvent viscosity; for example, ChCl:Glycerol is significantly more viscous than ChCl:Ethylene Glycol because glycerol has three -OH groups for H-bond formation compared to two in ethylene glycol (Munir et al., 2026). While excessively high viscosity can hinder matrix permeability and mass transfer, moderate viscosity may assist in trapping certain solute molecules during the extraction process (Wang et al., 2026; Munir et al., 2026). To optimize these effects, water is commonly added to both HBD types to reduce viscosity and improve the diffusion coefficient (Nadeeshani et al., 2026; Wang et al., 2026).

Selectivity and safety profiles also distinguish these two classes of solvents. Polyol-based NADES generally exhibit lower cytotoxicity and higher biocompatibility than those based on organic acids, making them more suitable for food and cosmetic applications (Munir et al., 2026). Additionally, polyols like glycerol have documented protein-stabilizing properties, which help maintain the structural integrity of sensitive biomolecules during extraction (Munir et al., 2026). In studies specific to orange peel waste, although many phenolic compounds are stable in acidic media, hesperidin specifically demonstrates better long-term stability and higher recovery in polyol-based systems like ChCl:Glycerol (Munir et al., 2026). This indicates that the HBD type must be selected based on its specific molecular affinity for the target compound, such as the binding energy between the solvent components and the bioactive solute (Liu et al., 2026; Munir et al., 2026).

Table 3. Comparison of organic acid and polyol HBDs

Parameter	Organic Acid HBDs (e.g., Lactic, Malic)	Polyol HBDs (e.g., Glycerol, Ethylene Glycol)
Acidity (pH)	Typically 0.0 – 2.0 (Munir et al., 2026)	Typically 1.6 – 5.0 (Munir et al., 2026)
Viscosity	High for malic acid (Wang et al., 2026)	Very high (glycerol) to low (ethylene glycol) (Munir et al., 2026)
Cytotoxicity	Generally higher (Munir et al., 2026)	Generally lower and safer (Munir et al., 2026)
Preferred Solutes	Anthocyanins, highly polar phenolic acids (Todorović et al., 2026; Munir et al., 2026)	Hesperidin, proteins, essential oils (Munir et al., 2026; Liu et al., 2026)
Mechanism	Cell wall hydrolysis via low pH (Munir et al., 2026)	Stabilization via dense H-bond network (Munir et al., 2026)

3.1.3 Influence of Water Content and Temperature

Water functions as a crucial modifier in ChCl-based natural deep eutectic solvents (NADES) by regulating their high intrinsic viscosity and adjusting their polarity. The addition of water, typically optimized in the range of 20% to 30% (w/w), disrupts the extensive hydrogen-bond network of the solvent, which enhances diffusivity and improves its ability to penetrate the biomass matrix. However, the proportion of water must be strictly controlled, as excessive hydration, frequently defined as exceeding 50%, can cause the system to lose its eutectic character and weaken the solvent-solute interactions, leading to a significant reduction in extraction yield (Munir et al., 2026).

Temperature serves as a key regulator of the physical properties of glyceline, directly impacting the solubility and mass transfer rates of target compounds. Increasing the extraction temperature results in a non-linear decrease in solvent viscosity, which improves molecular mobility and facilitates the disruption of plant cell membranes. For the extraction of flavonoids and phenolic compounds, optimum yields are frequently observed at moderate to high temperatures between 50°C and 80°C. While heating enhances extraction kinetics, it is necessary to avoid temperatures that exceed the stability limits of the target compounds to prevent irreversible thermal degradation or undesirable color changes (Munir et al., 2026).

The combination of moderate hydration and optimized temperature is particularly effective for the selective recovery of hesperidin, the primary polyphenol found in orange peel. ChCl-based solvents have demonstrated a specialized affinity for flavonoid structures, providing a stabilizing environment that protects these molecules from oxidative degradation more effectively than traditional organic solvents. In comparative studies, hesperidin not only showed higher extraction yields in ChCl:Glycerol but also maintained superior stability during storage compared to extracts obtained with more aggressive acidic DES formulations (Munir et al., 2026).

Table 4. Effects of water content and temperature on bioactive compound extraction using ChCl-based NADES

Parameter	Optimal Range/Trend	Impact on Extraction Performance
Water Content	20% – 30% (w/w)	Reduces viscosity and increases matrix permeability; excessive water (>50%) disrupts the eutectic structure.
Temperature	50°C – 80°C	Enhances solute solubility and diffusion coefficients; helps in cell wall disruption while avoiding degradation.
Viscosity	Non-linear decrease with temperature	Lower viscosity minimizes mass transfer resistance and improves solvent handling.
Selectivity	High for Flavonoids	Specifically increases the recovery and stability of hesperidin compared to ethanol.

(Munir et al., 2026)

3.1.4 Solvent Recyclability and E-factor

The recyclability of solvents is a fundamental criterion for ensuring the economic feasibility and environmental sustainability of extraction processes. Deep eutectic solvents (DESs) are frequently characterized by their low volatility and high stability, which facilitate a simpler and more sustainable recycling process compared to traditional organic solvents or ionic liquids (Farahi et al., 2026). This recyclable nature directly supports the principles of green chemistry by reducing the consumption of raw materials and minimizing the generation of hazardous waste (Ali et al., 2026). Furthermore, the ability to regenerate these solvents under mild conditions allows for a significant reduction in operational costs associated with large-scale industrial applications (Zhou et al., 2026).

Practical assessments have demonstrated that many deep eutectic solvents maintain their structural integrity and extraction performance over multiple reuse cycles. For example, some non-ionic DES systems have shown stable performance over five consecutive cycles without significant loss in selectivity or efficiency (Gholami et al., 2026). In biomass pretreatment and fractionation, recovered acidic DESs have maintained component retention rates exceeding 96% and stable pulping performance over three cycles (Zhou et al., 2026). Similarly, natural deep eutectic solvents have demonstrated robust reusability in catalytic processes for up to four cycles without losing activity (Zhu et al., 2026). These findings underscore the potential for closing the loop in recovery processes and achieving high-purity solvent restoration (Pereira et al., 2026).

To quantitatively evaluate the greenness of these processes, mass-driven metrics such as the environmental factor (E-factor) and process mass intensity (PMI) are employed. The E-factor is a critical indicator that measures the ratio of the total mass of waste generated to the total mass of the target product obtained (Gholami et al., 2026). By incorporating these metrics, researchers can compare the efficiency of different solvent systems and identify pathways to minimize the environmental footprint of extraction (Ali et al., 2026). For instance, a lower E-factor indicates a more efficient and environmentally benign process, aligning with the goal of minimizing solvent intensity and maximizing mass productivity (Gholami et al., 2026).

Table 5. Quantitative green metrics for solvent process assessment

Metric	Formula/Definition	Role in Assessment
Environmental Factor (E-factor)	$\frac{\text{Total mass of waste in raffinate}}{\text{Total mass of product in extract}}$	Quantifies waste generation relative to product recovery (Gholami et al., 2026).
Process Mass Intensity (PMI)	$\frac{(\text{Mass of feed} + \text{Mass of solvent phase})}{\text{Total mass of product in extract}}$	Measures the total mass required to produce a unit of product (Gholami et al., 2026).
Solvent Intensity (SI)	$\frac{\text{Total mass of solvent phase}}{\text{Total mass of product in extract}}$	Evaluates the efficiency of solvent utilization in the extraction process (Gholami et al., 2026).
Mass Productivity (MP %)	$\frac{\text{Total mass of product}}{\text{Total mass of feed and solvent}} \times 100$	Represents the percentage of input mass converted into target product (Gholami et al., 2026).

3.2 Discussion

3.2.1 Mechanisms of Enhanced Extraction Yield

The higher hesperidin recovery observed in choline chloride-based NADES compared to traditional organic solvents is primarily driven by the solvent's ability to disrupt plant cell wall structures and provide numerous hydrogen-bonding sites. By balancing viscosity and polarity to match the molecular structure of hesperidin, these eutectic mixtures facilitate more effective mass transfer from the biomass. For instance, specific formulations such as choline chloride-diethanolamine and optimized deep eutectic systems have demonstrated yields exceeding those of 70% ethanol. This suggests that the specialized chemical environment created by the eutectic mixture is more efficient at stabilizing and recovering polar flavonoids than conventional media like ethanol or acetone.

The specific mechanism of extraction is further influenced by the choice of hydrogen bond donor (HBD) and physical modifiers. While organic acid-based HBDs facilitate the release of intracellular compounds through cell wall hydrolysis at very low pH, polyol-based systems like ChCl:Glycerol provide a dense hydrogen-bonding network that is particularly effective for stabilizing hesperidin. The physical properties of these solvents are tuned by temperature and water content; adding 20% to 30% water disrupts the extensive H-bond network of the solvent, which reduces viscosity and improves matrix permeability. When combined with temperatures between 50°C and 80°C, the resulting increase in molecular mobility and solute solubility further enhances extraction kinetics without reaching the degradation limits of the target compounds.

3.2.2 Impact of HBD Selection on Hesperidin Stability

The selection of the hydrogen bond donor (HBD) fundamentally determines the chemical environment and the resulting stability of hesperidin during the extraction process. While organic acid-based HBDs, such as malic or lactic acid, facilitate the hydrolysis of plant cell walls through highly acidic conditions (pH 0.0–2.0), they often lack the stabilizing capacity required for long-term flavonoid recovery. In contrast, polyol-based systems like ChCl:Glycerol operate at higher pH levels and have demonstrated superior recovery and long-term stability for hesperidin compared to these acidic formulations. This suggests that the milder acidity of polyols is more compatible with maintaining the structural integrity of hesperidin.

The protective effect of polyol-based NADES is largely attributed to their dense internal hydrogen-bonding networks. For example, glycerol's three hydroxyl groups allow for a more robust network than ethylene glycol, which only possesses two. This specialized environment serves to "trap" the solute and shield it from oxidative degradation more effectively than both traditional organic solvents and aggressive acidic DES. Consequently, utilizing polyols as HBDs ensures that hesperidin remains stable during both the extraction phase and subsequent storage, making them the preferred choice for preserving this specific bioactive molecule.

3.2.3 Physical Property Tuning via Water and Temperature

The adjustment of water content is a fundamental strategy for managing the high intrinsic viscosity and polarity of ChCl-based NADES. Diluting the solvent within an optimal range of 20% to 30% (w/w) disrupts the extensive hydrogen-bond network, which enhances diffusivity and allows the solvent to penetrate the biomass matrix more effectively. However, the proportion of water must be carefully controlled; exceeding 50% hydration causes the system to lose its eutectic character. This structural breakdown weakens the necessary solvent-solute interactions, leading to a significant reduction in the recovery of bioactive compounds.

Temperature further regulates the physical properties of the solvent by inducing a non-linear decrease in viscosity, which improves molecular mobility and mass transfer rates. Maintaining temperatures between 50°C and 80°C facilitates the disruption of plant cell membranes and increases solute solubility without exceeding the stability limits of the target molecules. This combination of moderate hydration and optimized heating is particularly effective for hesperidin, as it provides a stabilizing environment that protects the flavonoid from oxidative degradation. Consequently, these tuned polyol-based systems demonstrate superior extraction yields and long-term stability for hesperidin compared to both traditional organic solvents and aggressive acidic DES formulations.

3.2.4 Economic Feasibility and Green Metrics

The economic viability of using choline chloride-based solvents is largely driven by their recyclability and high stability. Unlike traditional organic solvents, these systems exhibit low volatility, which facilitates a simpler regeneration process under mild conditions. This ability to recover the solvent directly supports the reduction of operational costs in industrial applications. Practical data shows that deep eutectic systems can maintain their structural integrity and extraction performance over three to five consecutive cycles. Specifically, recovered solvents have demonstrated component retention rates exceeding 96%, which allows for a closed-loop recovery process that minimizes raw material consumption and hazardous waste generation.

To quantitatively evaluate the environmental impact of these processes, mass-driven metrics such as the E-factor and Process Mass Intensity (PMI) are essential. The E-factor provides a clear measure of greenness by calculating the ratio of waste generated to the mass of the target product obtained. A lower E-factor indicates a more efficient process with a smaller environmental footprint, aligning with the goals of sustainable biomass utilization. Additionally, metrics like solvent intensity and mass productivity help identify pathways to maximize the conversion of input materials into the final product. By utilizing these metrics, the extraction of hesperidin can be optimized to ensure it is both environmentally benign and mass-productive.

4. CONCLUSION

Choline chloride-based natural deep eutectic solvents (NADES), particularly those utilizing polyol hydrogen bond donors like glycerol, provide a highly effective and sustainable medium for recovering hesperidin from citrus waste. Optimized extraction performance is achieved by maintaining a water content of 20% to 30% (w/w) and temperatures between 50°C and 80°C, which balances solvent viscosity with mass transfer efficiency. These systems not only outperform traditional organic solvents in yield and molecule stability but also demonstrate robust economic feasibility through high recyclability and retention rates exceeding 96% over multiple cycles. Consequently, the application of these green solvents supports the transition toward a circular bioeconomy by efficiently transforming industrial citrus by-products into high-value bioactive compounds.

REFERENCES

Abed, S. S., Mohammed, F. F., & Mohammed, T. (2026). Spectrophotometric determination of hesperidin using a flow injection technique based on azo dye formation with green analytical assessment. *Analytical Methods in Environmental Chemistry Journal*, *9*(1), 160–172. https://doi.org/10.24200/amecj.v9.i01.1110

Ali, A., Li, R., Zhu, R., Mahmood, S., Chen, Q., & Yao, S. (2026). Deep eutectic solvents for green extraction and separation of bioactive compounds from traditional Chinese medicines. *Chinese Medicine*, *21*, 38. https://doi.org/10.1186/s13020-026-01325-z

Farahi, S., Mortaheb, H. R., & Heydar, K. T. (2026). Molecular insights into acetonitrile-water separation by liquid-liquid extraction using water-choline chloride deep eutectic solvent. *Chemical Physics*, *607*, 113151. https://doi.org/10.1016/j.chemphys.2026.113151

Garg, R., Anjum, A., Garg, R., Eddy, N. O., & Watandost, H. (2026). Citrus fruits as sources of bioactive compounds for multifaceted applications. *Discover Food*, *6*(1). https://doi.org/10.1007/s44187-026-00897-x

Gholami, S., López-Porfiri, P., Pérez-Page, M., & Esteban, J. (2026). Selective extraction of platinum and palladium using reusable carvacrol-based deep eutectic solvents: Experimental and computational insights. *Separation and Purification Technology*, *395*, 137592. https://doi.org/10.1016/j.seppur.2026.137592

Jiang, J., Wu, Y., Gao, L., Shao, J., Shao, Y., Yu, L., Zheng, P., & Gu, J. (2024). The optimization of extraction process on Quzhou Fructus Aurantii flavonoids with natural deep eutectic solvents: A comparative study between orthogonal analysis and genetic neural network. *LWT*, *198*, 115936. https://doi.org/10.1016/j.lwt.2024.115936

Krekhova, F., Shishov, A., Meshcheva, D., & Bulatov, A. (2026). Deep eutectic solvents: extraction and derivatization. A review. *TrAC Trends in Analytical Chemistry*, *200*, 118851. https://doi.org/10.1016/j.trac.2026.118851

Lambangsari, K., Regita, A. G., Munawaroh, L., Simanjuntak, E. E. Y., Zafira, N. D., & Abduh, M. Y. (2025). Effects of fermentation time and extraction solvent on antioxidant activity and total phenolic and flavonoid content of phenolic extract from orange (*Citrus reticulata*) peel. *IIUM Engineering Journal*, *26*(1), 22–38. https://doi.org/10.31436/iiumej.v26i1.3173

Liu, Y., Zhou, L., Chen, S., Xiang, H., Huang, Y., Lai, Y., Zhang, L., & Li, H. (2026). Deep eutectic solvent-assisted extraction of cinnamaldehyde-rich cinnamon (*Cinnamomum cassia*) essential oil: enabled by molecular simulation and microwave-ultrasound pretreatment. *Food Chemistry*, *514*, 149107. https://doi.org/10.1016/j.foodchem.2026.149107

Munir, R., Muneer, A. R., Muneer, A., & Sultana, B. (2026). Glyceline (choline chloride-glycerol) (natural) deep eutectic solvents for bioactive compound extraction. *Talanta*, *306*, 129753. https://doi.org/10.1016/j.talanta.2026.129753

Nadeeshani, H., Hewage, A., Zhao, Y., Sá, A. G. A., House, J. D., & Bandara, N. (2026). Structure-functional properties and protein quality of climate-smart white lupin (*Lupinus albus*) protein isolates: Impact of deep eutectic solvent and conventional protein extraction methods. *Food Hydrocolloids*, *175*, 112528. https://doi.org/10.1016/j.foodhyd.2026.112528

Pereira, B. A., Costa, L., Crespo, J. G., & Brazinha, C. (2026). Recovery of C-phycocyanin from a natural deep eutectic solvent extractant. *Separation and Purification Technology*, *395*, 137837. https://doi.org/10.1016/j.seppur.2026.137837

Ren, D., Yang, Y., Fang, M., Xie, T., Li, K., Zhang, J., Zhuang, Y., & Yi, L. (2026). Synergistic effects of viscosity and Kamlet-Taft parameters in deep eutectic solvents for enhanced extraction of flavonoids from citrus waste. *Chemical Engineering Journal*, *533*, 174811. https://doi.org/10.1016/j.cej.2026.174811

Todorović, A. B., Cvetanović Kljakić, A. D., Sknepnek, A. S., Belošević, S. D., Salević, A. S., Mirković, M. M., Lević, S. M., & Nedović, V. A. (2026). Antioxidant and antimicrobial potential of blackberry polyphenolic extracts: Influence of different extraction techniques and solvents. *Food and Feed Research*, *53*(1). https://doi.org/10.5937/ffr0-60276

Wang, L., Fei, T., Li, X., Sun, Q., Liu, X., & Wang, L. (2026). Improved protein extraction from *Moringa oleifera* seeds using deep eutectic solvents: Mechanistic insights and protein characterization. *Food Hydrocolloids*, *174*, 112402. https://doi.org/10.1016/j.foodhyd.2025.112402

Wang, S., Feng, Y., Yu, X., Yang, Z., Jiao, P., & Niu, Q. (2025). Integrated deep eutectic solvent extraction and resin adsorption for recovering polyphenols from *citrus reticulata* Blanco peels: Process optimization, compositional analysis, and activity determination. *Separation and Purification Technology*, *355*, 129560. https://doi.org/10.1016/j.seppur.2024.129560

Zhou, J., & Tang, J. (2025). Extraction mechanism of hesperidin from *Citrus aurantium* L. using a novel deep eutectic solvent: Experimental and theoretical investigation. *Journal of the Brazilian Chemical Society*, *36*(4), e-20240175. https://dx.doi.org/10.21577/0103-5053.20240175

Zhou, S., Zhang, Z., Xu, J., Li, J., Zhang, W., & Chen, K. (2026). Sustainable hierarchical extraction of lignin with simultaneous recovery of acidic deep eutectic solvent. *Biomass and Bioenergy*, *212*, 109303. https://doi.org/10.1016/j.biombioe.2026.109303

Zhu, Z., Wang, Q., Bi, X., Liu, B., Hu, D., Cao, D., & Dong, J. (2026). Molecular insights into water-induced separation of a deep eutectic solvent for CO2 fixation into propylene carbonate. *Separation and Purification Technology*, *394*, 137290. https://doi.org/10.1016/j.seppur.2026.137290