Natural and Chemical Solvents Used for Extraction of Phytoactive Constituents: Techniques, Applications, and Future Perspectives*

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ABSTRACT

Extraction of Phytoactive constituents is a critical step in the development of plant-based therapeutics, nutraceutical and cosmetic formulations. The choice of solvent plays a pivotal role in influencing the efficiency, selectivity, and safety of the extracted bio actives. This review compares natural and chemical solvents used for extraction, focusing on their mechanisms, efficiency, sustainability, and regulatory acceptability. The discussion highlights conventional solvents such as ethanol, methanol, and hexane, alongside green alternatives including deep eutectic solvents (DES), ionic liquids, supercritical fluids, and natural deep eutectic solvents (NADES). Recent advances in solvent selection and extraction technologies are examined, with emphasis on phytochemical yields, toxicity, and industrial scalability. Applications across food, pharmaceuticals, and cosmetics are also reviewed.

Keywords: Phytoactive compounds, extraction solvents, green solvents, deep eutectic solvents, supercritical fluid extraction, natural products.

INTRODUCTION

Phytochemicals are bioactive compounds naturally occurring in plants that possess therapeutic, nutraceutical, and cosmetic properties. Their extraction is a crucial step in isolating specific molecules such as alkaloids, flavonoids, terpenoids, glycosides, and phenolic compounds. Traditional extraction relies heavily on organic chemical solvents, many of which are toxic, volatile, and environmentally hazardous. Recent shifts toward sustainable chemistry have introduced natural and green solvents as promising alternatives.

This review aims to summarize and compare the various natural and chemical solvents used in the extraction of phytoactive constituents, discuss their applications, and outline recent technological developments. The search for sustainable and eco-friendly alternatives to synthetic solvents has led to the investigation of herbal solvents. These solvents are primarily composed of extracts from plants, which possess unique properties that make them suitable for a variety of applications. (1)

Classification of Herbal Solvents

Herbal solvents can be classified based on their Chemical Classification and Biological Safety Rating. The latter is crucial as it provides insight into the safety of using these solvents in products that come into contact with humans.

BS Classification System

The Biological Safety (BS) classification system categorizes substances based on their potential risk to human health and the environment. The BS classification can generally be divided into four categories:

BS I: Low Risk – Herbal solvents that pose minimal health risks or irritations. Examples include water extracts and glycerin.

BS II: Moderate Risk – Solvents that may cause irritation or adverse effects in sensitive individuals. An example could be ethyl alcohol derived from herbal sources.

BS III: High Risk – Solvents that can cause significant adverse effects upon exposure. Certain essential oils may fall into this category.

BS IV: Extreme Risk – Highly toxic substances that pose severe health risks or are considered carcinogenic. Although rare, some herbal extracts may be classified here. (2)

Properties of Herbal Solvents

Herbal solvents typically exhibit properties such as good solubility, non-toxicity, low volatility, and safety for human consumption. Below are some prominent herbal solvents categorized by their origins and relevance.

Water Extracts: These are obtained via boiling plant materials in water and are considered the safest with a BS I classification. They are commonly used in herbal teas and infusions.

Glycerin: Plant-derived glycerin is an effective solvent in many applications. It generally falls under BS I due to its low toxicity level and suitability for food and cosmetic products.

Ethyl Alcohol: Derived from fermentation processes involving plant sugars, ethyl alcohol is classified as BS II. It's widely used in tinctures and as a preservative.

Essential Oils: Concentrated plant extracts with potent biological activity. They may vary in BS classification; many are BS II or even BS III depending on the plant source and concentration. (3)

HERBAL SOLVENTS

1. Olive Oil

Classification: BS I

Properties: Olive oil is non-toxic, biodegradable, and exhibits antioxidant properties. It's often used as a carrier oil in herbal preparations and cosmetic formulations.

Applications: Commonly used in food, as a carrier for essential oils in aromatherapy, and in skincare products.

2. Coconut Oil

Classification: BS I

Properties: Coconut oil is a versatile solvent that is rich in medium-chain fatty acids, which have antimicrobial properties.

Applications: Used in cosmetics, food, and as a base for herbal remedies; excellent for skin and hair care applications.

3. Ethanol from Sugarcane

Classification: BS II

Properties: Ethanol derived from sugarcane is often used as a solvent for its excellent solvent properties and relatively low toxicity.

Applications: Common in the pharmaceutical industry for extraction processes and as a preservative. (4)

4. Vegetable Glycerin

Classification: BS I

Properties: A clear, odorless liquid that is sweet-tasting and has hygroscopic properties. Safe for consumption and widely accepted in dietary supplements.

Applications: Used as a sweetener, humectant, and solvent in herbal formulations, as well as in cosmetics and personal care products.

5. Propylene Glycol

Classification: BS II

Properties: A synthetic organic compound that is safe for use in food, pharmaceuticals, and cosmetics. It acts as a solvent and humectant.

Applications: Often found in cosmetics, food additives, and pharmaceutical formulations. (5)

6. Animal Fats (e.g., Lard, Tallow)

Classification: BS I

Properties: Natural fats derived from animal sources are used in traditional herbal remedies for their emulsifying properties.

Applications: Incorporation in topical ointments and balms. (6)

7. Butter

Classification: BS I

Properties: Contains fats and water, offering an emollient effect, making it beneficial in topical applications.

Applications: Used in various cosmetic formulations and in traditional herbal remedies. (7)

8. Sesame Oil

Classification: BS I

Properties: Rich in antioxidants and has anti-inflammatory properties. Sesame oil is safe for use in food and cosmetic products.

Applications: Used in cooking, as a carrier oil for herbal extracts, in traditional medicine, and in skin care formulations. (8)

9. Jojoba Oil

Classification: BS I

Properties: Actually a wax ester, jojoba oil closely resembles human sebum, making it a great moisturizer and skin conditioner.

Applications: Widely used in cosmetics, personal care products, and for oil infusions in herbal remedies.(9)

10. Castor Oil

Classification: BS I

Properties: Known for its laxative properties; it is also a superlative emollient due to its high ricinoleic acid content.

Applications: Used in cosmetics, pharmaceuticals, and as a vehicle for herbal preparations. (10)

11. Avocado Oil

Classification: BS I

Properties: Contains monounsaturated fats and is rich in vitamins. It penetrates the skin well and has anti-inflammatory properties.

Applications: Commonly used in skin care products, hair treatments, and as a carrier oil for essential oils. (11)

12. Honey

Classification: BS I

Properties: A natural humectant with antibacterial and antimicrobial properties. It can dissolve water-soluble substances effectively.

Applications: Used in various traditional remedies, cosmetics, and food products. (12)

13. Lemon Juice

Classification: BS I

Properties: Has natural astringent and antiseptic properties. It is rich in citric acid and vitamin C.

Applications: Often used in culinary applications, natural cleaning products, and as an ingredient in herbal remedies. (13)

14. Rosewater

Classification: BS I

Properties: Acts as a natural astringent and has anti-inflammatory properties. It can also dissolve certain oil-soluble compounds.

Applications: Used in cosmetics, skincare, and culinary applications, particularly in Middle Eastern cuisine. (14)

15. Olive Oil

Classification: BS I

Properties: Rich in monounsaturated fats and antioxidants. It has anti-inflammatory and moisturizing properties.

Applications: Commonly used in cooking, as a carrier oil for herbal solutions, and in cosmetics and skin-care products. (15)

16. Peppermint Oil

Classification: BS I

Properties: Contains menthol, which has a cooling effect. It has analgesic and antimicrobial properties.

Applications: Used in aromatherapy, topical applications, and as a flavoring agent in foods (16).

17. Coconut Oil

Classification: BS I

Properties: High in saturated fats and medium-chain triglycerides, coconut oil is moisturizing and has antimicrobial properties.

Applications: Widely used in cooking, skin care, and hair care. It is also employed in herbal extractions. (17)

18. Grape Seed Oil

Classification: BS I

Properties: Rich in linoleic acid and vitamin E, it has antioxidant and anti-inflammatory properties.

Applications: Commonly used in cosmetics, mayonnaise, and salad dressing. (18)

19. Black Seed Oil

Classification: BS I

Properties: Rich in thymoquinone, it has anti-inflammatory, antioxidant, and antimicrobial properties.

Applications: Used in traditional medicine, cosmetics, and dietary supplements. (19)

20) Rosemary Oil

Classification: BS I

Properties: Contains antioxidants and anti-inflammatory compounds. It has potential neuroprotective effects and may improve circulation.

Applications: Used in cooking, cosmetics, and aromatherapy. It is also used for hair care products to promote hair growth. (20)

21). Lavender Oil

Classification: BS I

Properties: Known for its calming effects, lavender oil has anti-anxiety, analgesic, and antimicrobial properties.

Applications: Commonly used in aromatherapy, perfumes, and skin care products. (21)

22). Lemon Balm

Classification: BS I

Properties: Exhibits antibacterial, antiviral, and antioxidant properties. Known for its calming effects.

Applications: Used in teas, herbal remedies, and cosmetics for its soothing effects. (22)

23). Sandalwood Oil

Classification: BS I

Properties: Anti-inflammatory and antimicrobial properties. Often used in traditional medicine and perfumery.

Applications: Commonly used in cosmetic products, incense, and personal care products. (23)

24. Clove Oil

Classification: BS I

Properties: Contains eugenol with potent analgesic, anti-inflammatory, and antimicrobial properties.

Applications: Used in dental care, culinary applications, and traditional medicine. (24)

25. Cardamom Oil

Classification: BS I

Properties: Antioxidant, antimicrobial, and anti-inflammatory effects. Traditionally used for digestive health.

Applications: Used in culinary dishes, perfumes, and as an herbal remedy. (25)

26. Ginger Oil

Classification: BS I

Properties: Has anti-inflammatory and antioxidant properties.

Applications: Used in culinary practices, traditional medicine, and aromatherapy. (26)

27. Cinnamon Oil

Classification: BS I

Properties: Antimicrobial and anti-inflammatory properties, useful for digestive support.

Applications: Used as a flavoring agent, in traditional medicine, and in personal care (27)

28. Fennel Oil

Classification: BS I

Properties: Antimicrobial and antioxidant properties; may help with digestion.

Applications: Used in both culinary and medicinal applications, and in perfumes. (28)

29. Orange Oil

Classification: BS I

Properties: Antimicrobial and uplifting; often used for its mood-enhancing effects.

Applications: Common in food flavoring, fragrances, and cleaning products. (29)

ORGANIC SOLVENTS

According to British Standards (BS), extraction solvents can be classified based on their polarity, chemical structure, and application. The primary classifications include:

1. **Polar Solvents**: These solvents have a high dielectric constant and are effective in dissolving polar compounds. They are commonly used in the extraction of hydrophilic substances.
    - **Examples**: Water, Methanol, Ethanol, Acetonitrile.
2. **Non-Polar Solvents**: These solvents possess a low dielectric constant and are suitable for extracting non-polar compounds. They are often used in the extraction of lipophilic substances.

- **Examples**: Hexane, Toluene, Chloroform, Dichloromethane.

3. **Semi-Polar Solvents**: These solvents have intermediate polarity and can dissolve both polar and non-polar compounds. They are versatile and widely used in various extraction processes.
    - **Examples**: Ethyl Acetate, Acetone, Isopropanol.(30,31)

1. Ethanol (Ethyl Alcohol)

Classification: Universal solvent

Properties: Polar solvent, excellent for dissolving a wide range of polar and nonpolar substances; antibacterial properties.

Applications: Widely used in pharmaceuticals, cleaning products, and as a solvent in various chemical reactions. (32)

2. Acetone

Classification: Ketone solvent

Properties: Highly polar and volatile solvent; excellent for dissolving plastics and synthetic fibers.

Applications: Commonly used in nail polish remover, paint thinners, and in the production of plastics. (33)

3. Hexane

Classification: Hydrocarbon solvent

Properties: Non-polar solvent; effective for dissolving non-polar compounds and oils.

Applications: Commonly used in oil extraction, food processing, and as a laboratory solvent. (34)

4. Toluene

Classification: Aromatic hydrocarbon solvent

Properties: Non-polar solvent; good for dissolving organic compounds and resins.

Applications: Used in paint thinners, adhesives, and chemical formulations. (35)

5. Methanol

Classification: Simple alcohol solvent

Properties: Polar solvent; miscible with water and many organic solvents.

Applications: Used in antifreeze, solvents, and as a fuel source. (36)

6. Dichloromethane (Methylene Chloride)

Classification: Chlorinated solvent

Properties: Non-polar solvent; good at dissolving a range of organic compounds.

Applications: Used in paint stripping, degreasing, and in laboratory applications. (37)

7. Chloroform

Classification: Chlorinated hydrocarbon solvent

Properties: Non-polar; used to dissolve organic compounds.

Applications: Formerly used as an anesthetic and in the production of refrigerants. (38)

8. Ethyl Acetate

Classification: Ester solvent

Properties: Polar aprotic solvent; good for dissolving a range of organic compounds.

Applications: Commonly used in nail polish removers and as a solvent in chemical reactions. (39)

9. Propylene Glycol

Classification: Glycol solvent

Properties: Polar, hydrophilic solvent; safe for use in food and pharmaceuticals.

Applications: Widely used in food processing, cosmetics, and as an antifreeze. (40)

10. Isopropyl Alcohol (IPA)

Classification: Alcohol solvent

Properties: Polar solvent; effective disinfectant and degreaser.

Applications: Commonly used in household cleaning products and hand sanitizers. (41)

11. Acetone

Classification: Ketone solvent

Properties: Polar aprotic solvent; highly volatile and miscible with water.

Applications: Commonly used in nail polish removers, paint thinners, and chemical cleaning. (42)

12. N-Butanol

Classification: Alcohol solvent

Properties: Moderately polar; miscible with water and many organic solvents.

Applications: Used in coatings, adhesives, and as an antifreeze. (43)

13. Sodium Chloride Solution (Salt Water)

Classification: Aqueous solution

Properties: Polar solvent; used for dissolving ionic compounds.

Applications: Commonly used in biological and chemical laboratories as a solvent and diluent. (44)

14. Dimethyl Sulfoxide (DMSO)

Classification: Sulfoxide solvent

Properties: Highly polar; miscible with water and organic solvents.

Applications: Used in pharmaceutical applications, as a solvent for chemical reactions, and in biological research. (45)

15. Cyclohexane

Classification: Aliphatic hydrocarbon solvent

Properties: Non-polar solvent; useful for dissolving non-polar compounds.

Applications: Commonly used in organic synthesis, as a paint solvent, and in the production of chemical intermediates. (46)

16. Hexane

Classification: Aliphatic hydrocarbon solvent

Properties: Non-polar solvent; effective for dissolving non-polar compounds and oils.

Applications: Commonly used in oil extraction, food processing, and as a laboratory solvent. (47)

17. Ethanol

Classification: Alcohol solvent

Properties: Polar, miscible with water; generally regarded as safe for many applications.

Applications: Widely used in pharmaceuticals, cosmetics, and as a solvent in various chemical reactions. (48)

18. Acetonitrile

Classification: Nitrile solvent

Properties: Polar aprotic solvent; miscible with water and useful for dissolving a wide range of organic compounds.

Applications: Commonly used in high-performance liquid chromatography (HPLC) and as a solvent in chemical synthesis. (49)

19. Benzene

Classification: Aromatic hydrocarbon solvent

Properties: Non-polar solvent; highly effective for dissolving a variety of organic compounds.

Applications: Used in the manufacture of chemicals, dyes, and as a laboratory solvent. (50)

20. Diethyl Ether

Classification: Ether solvent

Properties: Highly volatile; good for dissolving organic compounds and used in extractions.

Applications: Commonly used in organic synthesis and as a laboratory solvent. (51)

21. Petroleum Ether

Classification: Hydrocarbon solvent

Properties: Non-polar; characterized by a range of aliphatic hydrocarbons.

Applications: Used in extraction processes, as a laboratory solvent, and for washing purposes in organic synthesis. (52)

22. Acetic Acid

Classification: Carboxylic acid solvent

Properties: Polar; miscible with water and most organic solvents.

Applications: Used in the production of various chemicals, as a solvent in organic reactions, and in food preservation. (53)

23. N, N-Dimethylacetamide (DMAc)

Classification: Amide solvent

Properties: Polar aprotic; good solvent for a variety of applications.

Applications: Used in the production of polymers and as a solvent in chemical reactions. (54)

24. 1, 4-Dioxane

Classification: Cyclic ether

Properties: Polar; good solvent for many organic and inorganic compounds.

Applications: Used in extraction processes, as a solvent in chemical reactions, and for plastic production. (55)

Supercritical Fluids (SCF)

Supercritical CO_2 is widely used due to its tunable polarity and non-toxicity.

* Ideal for thermolabile compounds (e.g., essential oils, lipids).

* Often combined with co-solvents like ethanol for enhanced polarity.

Example: Extraction of curcumin from *Curcuma longa provided a high-purity extract without residual solvents (56).

Natural Deep Eutectic Solvents (NADES)

* Formed from combinations of natural components (e.g sugars, amino acids, organic acids).

* Biodegradable, non-toxic, and suitable for food-grade applications.

* Emerging as alternatives for phenolics and glycosides extraction.

Example: A NADES composed of choline chloride and lactic acid extracted rutin from buckwheat efficiently (57).

Ionic Liquids (ILs)

* Organic salts with low melting points; tunable physicochemical properties.

* High solvating power, but environmental persistence is a concern.

* Often used in microextraction protocols.

Aqueous Enzymatic and Hydroalcoholic Systems

* Enzymes (e.g., cellulase, pectinase) combined with ethanol or water enhance extraction by degrading plant cell walls.

* Applied for polysaccharides and glycosides.

Future Perspectives and Challenges

Solvent innovation: Need for low-cost, recyclable, food-grade natural solvents.

Process intensification: Integration with ultrasound, microwave, or pressurized liquid extraction.

Regulatory framework: Harmonization for global acceptance of green solvent use.

Scalability: Industrial adoption of NADES and ILs remains limited due to viscosity, cost, and recovery issues.

Conclusion

The choice of solvent is integral to the successful extraction of phytoactive constituents. While chemical solvents are effective, their environmental and health impacts drive the

exploration of greener alternatives. Supercritical fluids, NADES, and enzyme-assisted systems show immense promise in providing sustainable, safe, and efficient extraction platforms. Future research must focus on optimizing these systems for industrial scalability and multi-component extraction.

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