Extraction of Bioactive Constituents from *Fagonia indica*: Implications for Green Nanotechnology

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Abstract

Fagonia indica (Zygophyllaceae) is a medicinally important plant widely distributed in arid and semi-arid regions of Asia and Africa and has been traditionally used for the management of various ailments, including inflammatory disorders, cancer, diabetes, and liver diseases. The increasing interest in plant-based nanotechnology has highlighted medicinal plants as valuable resources for the eco-friendly synthesis of metal nanoparticles. In this context, the present study focuses on the extraction of bioactive constituents from *Fagonia indica* leaves and their application in the green synthesis of silver nanoparticles. Different conventional and advanced extraction techniques are employed in medicinal plant research to obtain bioactive compounds efficiently, with the selection of method primarily influenced by factors such as thermal stability of phytoconstituents, solvent nature, cost, extraction duration, final extract volume, and intended use. Among these methods, Soxhlet extraction was selected in the present work due to its high extraction efficiency and suitability for heat-stable phytochemicals. Fresh leaves of *Fagonia indica* were shade-dried, powdered, and subjected to Soxhlet extraction using ethanol as the solvent to obtain a concentrated leaf extract. The ethanolic extract served as a natural reducing and stabilizing agent for the green synthesis of silver nanoparticles, providing an environmentally benign alternative to conventional chemical synthesis methods. The use of plant-mediated synthesis minimizes the involvement of hazardous chemicals while improving biocompatibility. Overall, this study highlights the relevance of optimized extraction strategies in harnessing the phytochemical potential of Fagonia indica and demonstrates its applicability in the sustainable synthesis of silver nanoparticles for potential pharmaceutical and biomedical applications.

Keywords- Bioactive Compound, Medicinal plants, Soxhlet Extraction, *Fagonia indica*

Introduction

Fagonia is an important genus of the family *Zygophyllaceae*, comprising several species distributed across diverse phytogeographical regions worldwide and adapted to a wide range of environmental and climatic conditions. Among these, *Fagonia indica* (*Zygophyllaceae*), commonly known as Dhamasa, Dhamana, Sachi Booti, and Shoka'a, is predominantly found in the arid and semi-arid regions of Asia and Africa. The plant has been extensively utilized in traditional systems of medicine and is well recognized for its broad spectrum of therapeutic activities, including antidiabetic, anticancer, antileishmanial, antipyretic, anti-inflammatory, laxative, gastroprotective, hepatoprotective, and antioxidant effects. Despite its widespread ethnomedicinal use, comprehensive **in vitro** and **in vivo** studies are still required to elucidate the precise molecular mechanisms underlying its pharmacological actions and to establish robust scientific validation (Ali et al., 2016).

Nanotechnology represents a rapidly advancing interdisciplinary field focused on the design, synthesis, and manipulation of materials at the nanoscale. Owing to their unique physicochemical properties, nanomaterials have found extensive applications across diverse sectors, including public health, medicine, pharmaceuticals, food technology, agriculture, environmental remediation, and cosmetics. Among various metal-based nanomaterials, silver nanoparticles (AgNPs) have garnered considerable attention due to their exceptional electrical, optical, and magnetic properties. These characteristics render AgNPs highly suitable for applications such as antimicrobial agents, biosensors, electronic components, composite fibers, membranes, and cryogenic superconducting materials (Altemimi et al., 2017).

In recent years, the green synthesis of nanoparticles using medicinal plants has emerged as an eco-friendly, sustainable, and cost-effective alternative to conventional chemical and physical synthesis methods. Plant extracts function as natural reducing, stabilizing, and capping agents owing to the presence of diverse bioactive phytoconstituents, thereby minimizing the use of hazardous chemicals and reducing environmental toxicity. In this context, *Fagonia indica*, with its rich phytochemical composition, represents a promising biological resource for the green synthesis of silver nanoparticles.

Methods Used in the Extraction of Medicinal Plants

A variety of techniques are employed for the extraction of bioactive constituents from medicinal plants. While several conventional extraction methods remain widely practiced, newer techniques continue to evolve, and existing methodologies are being optimized to enhance extraction efficiency, selectivity, and yield (Altemimi et al., 2017; Bhan, 2017). The selection of an appropriate extraction method is a critical step and is largely determined by the nature of the plant material and the intended application of the extract.

Factors Influencing the Selection of an Extraction Method

(a) Thermal stability of plant constituents:
Heat-stable plant materials are commonly extracted using techniques such as Soxhlet extraction or microwave-assisted extraction. In contrast, thermolabile compounds are preferably extracted using milder techniques, including maceration or percolation, to prevent thermal degradation (Azwanida, 2015; Puri et al., 2014).

(b) Nature of the solvent:
The choice of solvent plays a pivotal role in determining extraction efficiency and selectivity. Aqueous solvents are generally suitable for maceration, whereas volatile organic solvents are more appropriate for Soxhlet extraction or percolation methods.

(c) Cost of the crude drug:
Inexpensive crude drugs are typically extracted using maceration due to its simplicity and low operational cost. Conversely, costly crude drugs are preferentially extracted by percolation to maximize extraction efficiency and yield (Azwanida, 2015; Puri et al., 2014).

(d) Duration of extraction:
Maceration is suitable for plant materials that require prolonged contact with the solvent. However, when rapid extraction is desired, advanced techniques such as microwave-assisted or ultrasound-assisted extraction are preferred.

(e) Final volume of the extract:
Large-volume preparations, such as tinctures, are commonly produced using maceration. In contrast, concentrated extracts are typically obtained through percolation or Soxhlet extraction.

(f) Intended use of the extract:
Extracts intended for human consumption are generally prepared using mild extraction techniques, such as maceration, to preserve bioactivity and safety. In contrast, extracts intended for experimental, analytical, or industrial applications may be prepared using more exhaustive methods, including Soxhlet extraction, percolation, or advanced extraction techniques.

Commonly Used Methods for the Extraction of Medicinal Plants

The extraction of bioactive constituents from medicinal plants is a critical step in phytochemical and pharmacological investigations. A variety of conventional and advanced extraction techniques are employed depending on the physicochemical nature of the plant material, the stability of the target compounds, and the intended application of the extract.

(i) Maceration

Maceration is one of the simplest and most widely employed extraction techniques. In this method, coarsely powdered plant material—such as leaves, stem bark, or root bark—is placed in a suitable container and completely immersed in the selected menstruum. The container is tightly closed and allowed to stand for a minimum period of three days. During this period, the contents are stirred periodically, or the container is shaken at regular intervals to enhance solvent penetration and extraction efficiency (Azwanida, 2015; Puri et al., 2014; Doughari, 2012; Harborne, 1998; Hossain et al., 2014; Ingle et al., 2017; Jacob et al., 2012).

At the end of the extraction period, the liquid extract (micelle) is separated from the solid residue (marc) by filtration or decantation. The micelle is subsequently concentrated by solvent evaporation using an oven or water bath. Maceration is particularly suitable for the extraction of thermolabile compounds, as it does not involve the application of heat.

(ii) Infusion

Infusion is a mild extraction technique similar to maceration and is commonly employed for the extraction of readily soluble bioactive constituents. In this process, finely powdered plant material is placed in a clean container, and the extraction solvent—either hot or cold—is poured over it. The mixture is allowed to stand for a short duration to facilitate the diffusion of soluble compounds into the solvent (Azwanida, 2015; Puri et al., 2014; Doughari, 2012).

This method is particularly suitable for the preparation of fresh extracts intended for immediate use. The solvent-to-drug ratio typically ranges from 4:1 to 16:1, depending on the nature and intended application of the extract.

(iii) Digestion

Digestion is a modification of maceration that involves the application of gentle heat to enhance extraction efficiency. In this method, the powdered plant material is mixed with the extraction solvent and subjected to controlled heating, usually at approximately 50 °C, using a water bath or oven (Puri et al., 2014; Doughari, 2012). The application of moderate heat reduces solvent viscosity and improves the diffusion of bioactive constituents into the solvent, thereby accelerating the extraction process.

(iv) Decoction

Decoction is a continuous hot extraction method that employs water as the extraction solvent. In this technique, dried and finely powdered plant material is transferred into a clean container, and a measured volume of distilled water is added. The mixture is stirred thoroughly and subjected to continuous heating, typically for about 15 minutes.

The solvent-to-drug ratio is maintained at either 4:1 or 16:1, depending on the intended use of the extract.

This method is particularly suitable for the extraction of water-soluble and heat-stable constituents. After completion of the extraction, the mixture is allowed to cool and filtered to obtain a clear decoction.

(v) Percolation

Percolation is an efficient extraction technique commonly used for the preparation of fluid extracts and tinctures. The method is carried out using a percolator, a narrow cone-shaped glass apparatus with openings at both ends. Initially, dried and finely powdered plant material is moistened with the selected solvent and allowed to stand for approximately 4 hours to ensure uniform wetting. The moistened material is then transferred into the percolator with the lower outlet closed and allowed to macerate for 24 hours.

After maceration, fresh solvent is added from the top, and the lower outlet is opened to allow the extract to percolate slowly under gravitational force. Additional solvent is continuously added to maintain saturation. The process is continued until approximately 75% of the total intended solvent volume is collected. The extract is filtered, and the residual marc is pressed to recover the remaining solvent. The final volume is adjusted using fresh solvent to obtain the desired concentration.

(vi) Soxhlet Extraction

Soxhlet extraction, also known as continuous hot extraction, is performed using a standard Soxhlet apparatus consisting of a round-bottom flask, extraction chamber, siphon tube, and condenser. Dried and finely powdered plant material is placed in a porous thimble and inserted into the extraction chamber, while the selected solvent is added to the round-bottom flask.

Upon heating, the solvent evaporates, condenses, and percolates through the plant material. When the solvent level reaches the siphon tube, it is siphoned back into the flask carrying the extracted phytoconstituents. This cycle is repeated continuously until complete extraction is achieved.

Following extraction, the solvent is removed by evaporation to obtain the crude extract. Soxhlet extraction is suitable for heat-stable compounds and plant materials that are partially soluble in the selected solvent but is not recommended for thermolabile constituents. The method offers high extraction efficiency, reduced solvent consumption, and eliminates the need for filtration (Azwanida, 2015; Puri et al., 2014; Majekodunmi, 2015).

Limitations:
Prolonged exposure to high temperatures may lead to degradation of heat-sensitive compounds, and the method does not allow agitation during extraction (Harborne, 1998; Pandey et al., 2014).

(vii) Microwave-Assisted Extraction (MAE)

Microwave-assisted extraction is an advanced technique based on dipole rotation and ionic conduction resulting from the interaction of microwave energy with polar molecules and ions present in the plant matrix and solvent. The extraction is performed using electromagnetic radiation in the frequency range of 300 MHz to 300 GHz, commonly at 2450 MHz with a power output of 600–700 W.

Microwave irradiation generates rapid internal heating, enhancing solvent penetration and facilitating the release of secondary metabolites. Polar solvents are preferred due to their efficient interaction with microwave energy. MAE is particularly effective for the extraction of flavonoids and other phenolic compounds, significantly reducing extraction time and solvent consumption while improving yield (Puri et al., 2014; Majekodunmi, 2015).

Limitations:
Localized overheating may cause degradation of heat-sensitive compounds such as tannins and anthocyanins, limiting its application to relatively heat-stable constituents (Harborne, 1998; Pandey et al., 2014).

(viii) Ultrasound-Assisted Extraction (UAE)

Ultrasound-assisted extraction employs high-frequency sound waves (>20 kHz) to enhance the extraction of bioactive compounds. Finely powdered plant material is mixed with a suitable solvent and subjected to ultrasonic waves in an ultrasonic extractor.

The ultrasound waves generate cavitation within the solvent, leading to disruption of plant cell walls and increased solvent penetration. This results in improved mass transfer and enhanced release of secondary metabolites into the solvent.

Advantages:
UAE offers reduced extraction time and solvent usage, improved extraction efficiency, and is suitable for small sample sizes.

Limitations:
Reproducibility may be affected by variations in ultrasonic intensity and exposure time. Excessive ultrasonic energy may also cause degradation of phytochemicals due to free radical formation (Azwanida, 2015; Doughari, 2012; Majekodunmi, 2015).

Materials and Methods

Extraction of *Fagonia indica* Leaves

Fresh leaves of *Fagonia indica* were collected and thoroughly washed with running tap water to remove dust and adhering impurities. The cleaned leaves were initially air-dried and subsequently shade-dried at room temperature for a period of 2–4 weeks. Direct exposure to sunlight was strictly avoided to prevent the degradation of thermolabile and photosensitive bioactive constituents.

Following complete drying, the leaves were finely powdered using a mechanical grinder and stored in airtight containers until further use. Approximately 50 g of the dried leaf powder was subjected to Soxhlet extraction using ethanol as the extraction solvent. The extraction was performed using a heating mantle and continued until exhaustive extraction was achieved. The resulting ethanolic extract was concentrated by solvent evaporation and stored in sterile, airtight containers at room temperature until further use for the synthesis of silver nanoparticles (Rizvi et al., 1996).

Conclusion

The present study emphasizes the significance of *Fagonia indica* as a valuable medicinal plant and a promising biological resource for nanotechnology-based applications. A systematic evaluation of medicinal plant extraction techniques underscores the importance of selecting appropriate methods based on phytochemical stability, solvent characteristics, extraction efficiency, and intended application. Among the various extraction approaches discussed, Soxhlet extraction using ethanol was found to be suitable for obtaining a concentrated leaf extract rich in bioactive constituents. The ethanolic extract of *Fagonia indica* was effectively utilized for the green synthesis of silver nanoparticles, demonstrating the dual role of plant phytochemicals as natural reducing and stabilizing agents. This plant-mediated synthesis approach offers a sustainable, cost-effective, and environmentally friendly alternative to conventional chemical and physical nanoparticle synthesis methods, which often involve toxic reagents and harsh conditions. The integration of traditional medicinal knowledge with modern nanotechnological techniques provides a novel platform for developing biocompatible nanomaterials. The findings of this study support the potential of *Fagonia indica* –based extracts in the synthesis of metal nanoparticles and highlight the broader applicability of green nanotechnology in pharmaceutical and biomedical research. Further investigations involving detailed physicochemical characterization and biological evaluation are warranted to fully explore the therapeutic potential of the synthesized nanoparticles.

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