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Unraveling the impact of Invasive species on native plants and aquatic ecosystems: A Comprehensive Analysis"

Reeta Akram[1], Abdul Muqeet[2], Samra Mahmood[3], Fareeda Tahir[3], Iffat Riaz[4], Muhammad Nauman[3], Abid Hussain[5] and Muhammad Sikandar[4]

[1]Department of Institute of Molecular Biology and Biotechnology, the University of Lahore, **Pakistan**
[2]Department of Entomology, University of Agriculture Faisalabad, **Pakistan**
[3]Department of zoology, University of Sargodha, **Pakistan**
[4]Department of Zoology, University of Agriculture Faisalabad-38000, **Pakistan**
[5]Department of Physics, Government College University Faisalabad-38000, **Pakistan**

***Correspondence:** muhmmadsikandar2929@yahoo.com **Received:** 01- 08- 2023 **Accepted: 30-08-23 Published online:** 02-09-23

The advantages and drawbacks of invasive plants and explores the potential of utilizing bioactive compounds extracted from these plants as natural reducing and capping agents for green bionanoparticle fabrication. The invasive plants are rich sources of diverse bioactive molecules, including stilbene derivatives (piceatannol, resveratrol, and quadrangularin-A), flavonoids, and triterpenoids, which significantly impact the formation, characterization, and biomedical performance of nanoparticles such as Ag, Au, ZnO, and CuO. The resulting invasive plant-mediated bio nanoparticles exhibit exceptional antibacterial and antifungal activities, suggesting their potential as valuable therapies against infectious diseases. Moreover, these bio nanoparticles show promise as potential anticancer agents and antioxidants. The mechanisms underlying the biomedical activities of invasive plant-mediated bio-nanoparticles are also discussed. Harnessing invasive species for bio nanoparticle synthesis can mitigate their negative impacts and economic losses. Furthermore, the bio nanoparticles synthesized using invasive plant extracts open new frontiers in biomedical applications, therapeutic treatments, and smart agriculture. This review highlights the significant potential of invasive plants and their bioactive compounds in the field of bio nanoparticle synthesis and their diverse biomedical applications

Keywords: Invasive species, native plants, aquatic ecosystems

INTRODUCTION

Invasive species are undoubtedly recognized as a significant global threat to both biodiversity and human society. Through clear logical reasoning, we can understand the detrimental impacts they have on ecosystems, economies, and human well-being (Bongaarts 2019). The coming decade is likely to witness an acceleration of new invasions unless large-scale coordinated prevention measures are undertaken. This prediction is based on several key global factors that contribute to the spread of invasive species, such as increased trade, travel, climate change, and socio-economic shifts. By examining these factors logically, we can understand the need for proactive and coordinated efforts to prevent further invasions. Firstly, increased trade and travel have facilitated the unintentional introduction of invasive species to new regions. Globalization has led to a significant rise in the movement of goods and people across borders. Invasive species can hitchhike on cargo, packaging materials, or transportation vehicles, allowing them to be transported to distant locations. Similarly, travelers can unknowingly carry invasive species through personal belongings or as stowaways in luggage. As trade and travel continue to grow, the risk of introducing new invasive species into different ecosystems also increases (Essl, Lenzner et al. 2020). The staggering costs and limited feasibility of invasive species control and eradication underscore the critical importance of large-scale coordination to prevent the introduction and establishment of new invasive species. By investing upfront in prevention measures, as well as implementing early detection and rapid response (EDRR) strategies, we can achieve substantial cost savings and prevent significant ecological disruptions. This logical analysis highlights the need for proactive and coordinated efforts to combat the spread of invasive species (Pimentel and Zuniga 2005).Over the past decade, nanotechnology has witnessed remarkable breakthroughs that have significantly contributed to modern scientific inventions. Nanotechnology, the field that focuses on manipulating matter at the atomic and molecular scale, has opened new possibilities and revolutionized various industries. In a logical progression, these breakthroughs have paved the way for advancements in electronics, medicine, energy, materials science, and many other fields (Mohajershojaei, Mahmoodi 2015). Nanoparticles indeed play a central role in the evolution of nanotechnology. Nanoparticles are particles with a nominal diameter of less than 100 nanometers. These particles possess unique physicochemical features that distinguish them from their bulk or submicron-sized counterparts. These distinctive properties arise due to size-dependent phenomena that occur at the nanoscale. One of the significant characteristics of nanoparticles is their increased surface-to-volume ratio compared to larger particles. As the size of a particle decreases, the relative surface area available per unit mass or volume increases significantly. This enlarged surface area provides nanoparticles with enhanced reactivity and the ability to interact more readily with their surroundings. Consequently, nanoparticles can exhibit different chemical, physical, and optical properties compared to bulk materials of the same composition (Brar, Magdouli 2022). In recent years, the use of plant sources as reducing agents in the creation of metallic bio nanoparticles has gained attention, leading to the emergence of Phyto-nanotechnology. This approach takes advantage of the significant benefits offered by Mother Nature. Phytochemical synthesis has been found to enable the rapid, cost-effective, and high-yield production of bio nanoparticles, aligning with the principles of sustainable development. The synthesis of metallic bio nanoparticles using plant extracts involves the use of phytochemicals present in various plant parts, such as leaves stems, roots, and fruits. These phytochemicals, including flavonoids, phenols, terpenoids, and alkaloids, possess reducing and stabilizing properties. When mixed with metal salts, they facilitate the reduction of the metal ions, resulting in the formation of nanoparticles (Naikoo and Mustaqeem 2021). Indeed, invasive plants often possess secondary substances that serve various functions, including allelopathy and chemical defense against herbivory. These substances can exhibit potent biological activities, and while they may be toxic, they also hold the potential to be a valuable resource for the development of plant-derived medicines. Allelopathy is a phenomenon in which certain plants release chemical compounds into their environment, inhibiting the germination, growth, or development of neighboring plants. These allelochemicals can suppress the growth of other plant species, providing invasive plants with a competitive advantage in their new environments. The allelopathic properties of invasive plants are often attributed to secondary metabolites such as phenolics, alkaloids, and terpenoids. Similarly, invasive plants have developed chemical defense mechanisms to protect themselves from herbivory. They produce toxic or deterrent compounds that can repel or harm herbivores, reducing the likelihood of being consumed. These chemical defenses are often responsible for the unpalatability or toxicity of certain invasive plant species. Examples of such compounds include alkaloids, tannins, and glycoside (McGaw and Omokhua-Uyi 2022). The assessment of invasive alien species in various fields, such as their application as bio-based adsorbents for environmental remediation or the production of biochars for multiple utilizations, highlights the potential benefits and opportunities that can arise from managing and utilizing invasive plants effectively. In the context of environmental remediation, invasive plant species have been explored for their potential as bio-based adsorbents. These plants possess characteristics that make them suitable for adsorption processes, such as high biomass production, large surface areas, and the presence of specific chemical compounds that can interact with pollutants. By harnessing these properties, invasive plants can be used to remove contaminants from soil, water, and air, contributing to the remediation of polluted environments. The utilization of invasive plants in this context offers a sustainable and cost-effective alternative to traditional remediation methods (Feng, Wang et al. 2021, Nguyen, Nguyen et al. 2022). (Prabakaran, Li et al. 2019) also suggest invasive plants can play a vital role in the phytoremediation of environmental contaminants. Phytoremediation is a plant-based approach that utilizes the natural abilities of plants to remove, degrade, or immobilize pollutants from soil, water, or air. In the context of invasive plants, their rapid growth, adaptability, and tolerance to various environmental conditions can make them effective phytoremediators (Prabakaran, Li et al. 2019).

MATERIAL AND METHODS

Ecological Impacts and Management of Invasive Plants: Assessing Harms and Benefits

2.1: Impacts and Challenges of Invasive Plants: Understanding the Harmful Effects

The Earth is currently facing a significant challenge in the form of invasive species, with more than 1000 of them spreading and thriving in various ecosystems. These invasive species pose a critical threat to the native and indigenous plants that have naturally evolved and adapted to their respective environments. The primary concern with invasive species lies in their ability to outcompete and displace native plants. Invasive plants often possess certain traits that give them a competitive advantage, such as rapid growth, high reproductive capacity, efficient resource utilization, and resistance to pests and diseases. These traits enable them to dominate habitats, depriving native plants of essential resources such as sunlight, water, nutrients, and space (Nguyen and Nguyen 2022). Invasive plants exhibit distinct characteristics that enable them to progress through five stages of biological invasion: introduction, establishment, spread, impact, and management. Understanding these stages and the traits that contribute to their invasiveness is crucial for developing strategies to prevent and manage the harmful effects of invasive plant species on ecosystems and human activities (Paz-Kagan and Silver 2019). The impacts of invasive species in aboveground and belowground ecosystems, particularly in forests, can occur through both direct and indirect pathways. These impacts can have significant consequences for ecosystem structure, function, and biodiversity. Direct impacts refer to the immediate effects caused by invasive species on the aboveground and belowground components of the ecosystem (Wardle and Peltzer 2017).

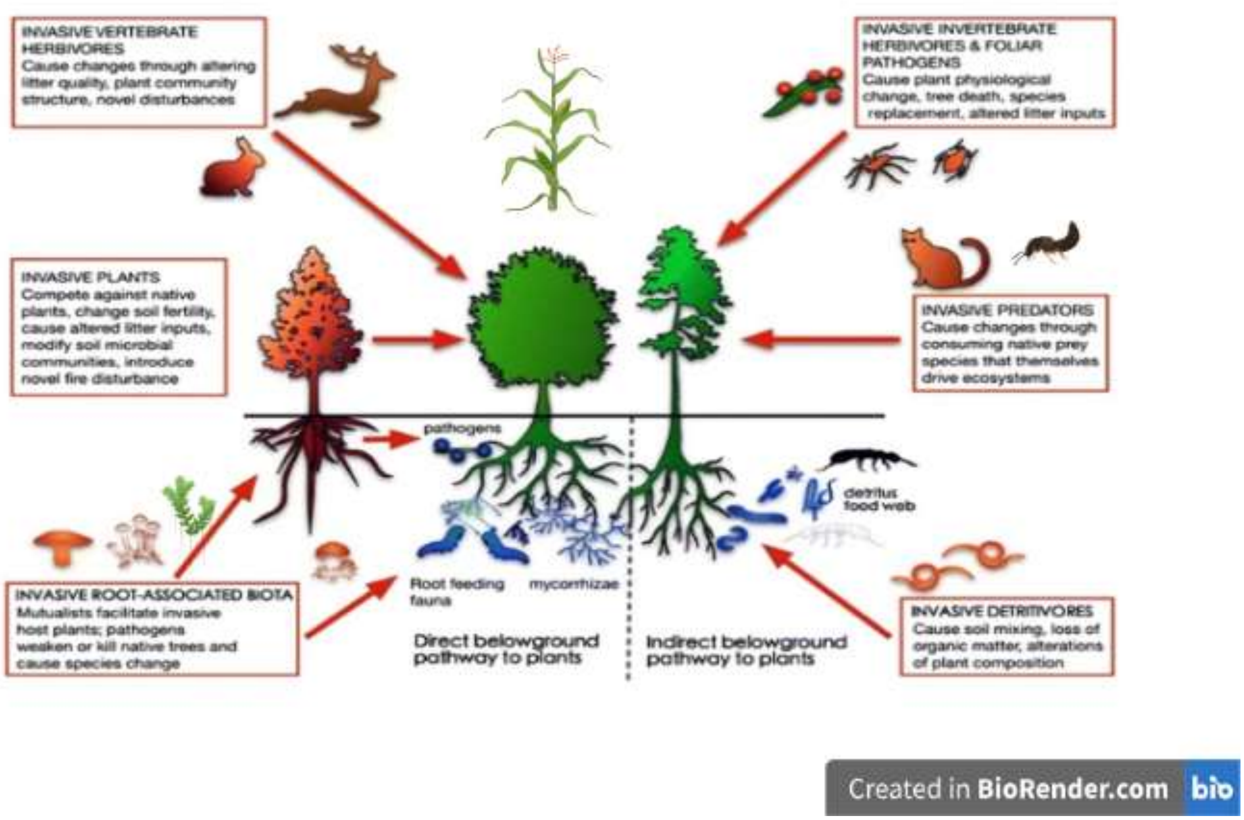

Figure 1: **An illustration of the impacts of invasive species in aboveground and belowground forest ecosystems can be seen through direct pathways, such as the interactions between soil organisms and plant roots.**

Invasive plants can disrupt the natural balance of belowground ecosystems by altering the interactions between plant roots and soil organisms like mycorrhizal fungi or beneficial bacteria. These disruptions can hinder nutrient uptake by native plants, affecting their growth and overall health.

On the other hand Invasive plants can indeed have additional negative impacts, including the reduction of water quality, increased fire risk, and soil erosion. In aquatic environments, invasive aquatic weed species can dominate water bodies, leading to a decrease in water quality. They can impede water flow, block sunlight, and deplete dissolved oxygen levels, which are essential for the survival of aquatic plants and animals. Some invasive aquatic plants also release toxic allelochemicals, further contributing to the decline of native aquatic organisms. To address the issue of invasive aquatic plants, mechanical harvesters are often utilized. These machines are designed to mechanically remove excessive vegetation from water bodies, helping to control the spread of invasive species and restore the balance of the aquatic ecosystem. Mechanical harvesting can be an effective management technique when used in conjunction with other control methods, such as manual removal, chemical treatments, or biological control, depending on the specific circumstances and requirements of the affected water body (Greenwood, Baumann et al. 2018, Waltham, Pyott et al. 2020). In another study A study conducted on the invasive plant Himalayan Balsam (Impatiens glandulifera) in the Ibach river system, UK, examined its effects and found a potential association between this species and areas experiencing high erosion. Invasive plants, including grasses and shrubs, often possess a cluster root system, which may have a weak binding capacity to the soil. Consequently, areas with invasive plant cover are more susceptible to erosion caused by flowing water, resulting in the loss of sediments and nutrients from the soil. The presence of invasive plants, such as Himalayan Balsam, can lead to increased vulnerability of the soil to erosion. Their shallow root systems and limited soil-binding capabilities make the ground cover less stable and more easily dislodged by water flow. As a result, sediments and essential nutrients present in the soil can be washed away, negatively impacting the health and fertility of the ecosystem (Greenwood, Baumann et al. 2018, Rai and Singh 2020). In conclusion, invasive plants have significant detrimental effects on native plants and the environment due to their unique invasion mechanisms. The Oregon Invasive Species Council estimates that invasive plants result in an annual economic loss of 120 billion dollars in the United States, equivalent to 1% of the gross domestic product. This economic impact encompasses losses in agricultural crops, expenses associated with control efforts, and the costs of damage inflicted by invasive plants.The harm caused by invasive plants extends beyond direct economic losses. They can outcompete native plants, reducing biodiversity and disrupting ecological balance. Invasive plants can also negatively impact ecosystem functions, such as nutrient cycling, water availability, and habitat quality for native wildlife. These cumulative effects highlight the urgency of addressing the issue of invasive plants through effective management, prevention, and control measures (Marbuah and Gren 2014).

Ecological and Economic Implications of Invasive Plants

Invasive plants possess secondary substances that serve various functions, such as allelopathy, which inhibits the growth and development of neighboring species, and chemical defense against herbivores. While these substances are known for their toxicity and potent biological activity, they also hold potential as valuable resources for developing plant-derived medicines. By studying and understanding these secondary compounds, we can explore their dual nature and uncover their potential benefits in the field of medicine (McGaw, Omokhua-Uyi et al. 2022). One compelling example is *Tithonia diversifolia*, an invasive shrub-like plant belonging to the Asteraceae family. It is prevalent in several regions, notably in Africa and South America, where it has been traditionally used to treat a diverse array of ailments. These include but are not limited to diabetes, measles, malaria, gastric ulcers, menstrual pains, snake bites, and wounds. Despite being considered an invasive species, Tithonia diversifolia showcases the potential for invasive plants to harbor medicinal properties that have been harnessed by local communities for generations. Exploring the chemical composition and pharmacological properties of such plants can lead to the discovery of novel therapeutic applications and contribute to the development of effective plant-based treatments for various health conditions (Ajao and Moteetee 2017). Through bioassay-guided phytochemical investigations, the extracts obtained from Tithonia diversifolia have revealed a rich repertoire of bioactive components with significant therapeutic potential and favorable safety profiles. Various parts of the plant, including leaves, roots, and stems, have been found to contain alkaloids, flavonoids, terpenoids, tannins, saponins, and phenols. Additionally, the aqueous and methanolic extracts derived from the shoots of the plant have been shown to contain substantial quantities of glycosides. These diverse bioactive compounds present in Tithonia diversifolia provide a promising foundation for further research and exploration, aiming to develop effective treatments derived from this invasive plant species. The identification and characterization of these compounds contribute to our understanding of its medicinal properties and open doors for potential therapeutic applications in the future (Tagne, Marino et al. 2018).

Cyperus rotundus, an invasive plant belonging to the Cyperaceae family, is widely utilized in various Asian countries, particularly Pakistan and India, for its medicinal properties. It has been traditionally employed in the treatment of ailments such as worms, diarrhea, fever, dysentery, menstruation issues, and stomach diseases. Despite its invasive nature, Cyperus rotundus holds a significant place in traditional medicine systems, where its therapeutic benefits have been recognized and utilized for generations. The plant's medicinal properties are attributed to its bioactive compounds, which may include alkaloids, flavonoids, phenols, terpenoids, and other secondary metabolites. These compounds are believed to contribute to the plant's pharmacological activities and therapeutic effects. By harnessing the knowledge of traditional medicine and conducting scientific investigations, researchers can further explore the chemical composition and pharmacological potential of Cyperus rotundus. This exploration may lead to the development of evidence-based treatments and contribute to the advancement of modern medicine (Bezerra and Pinheiro 2022).

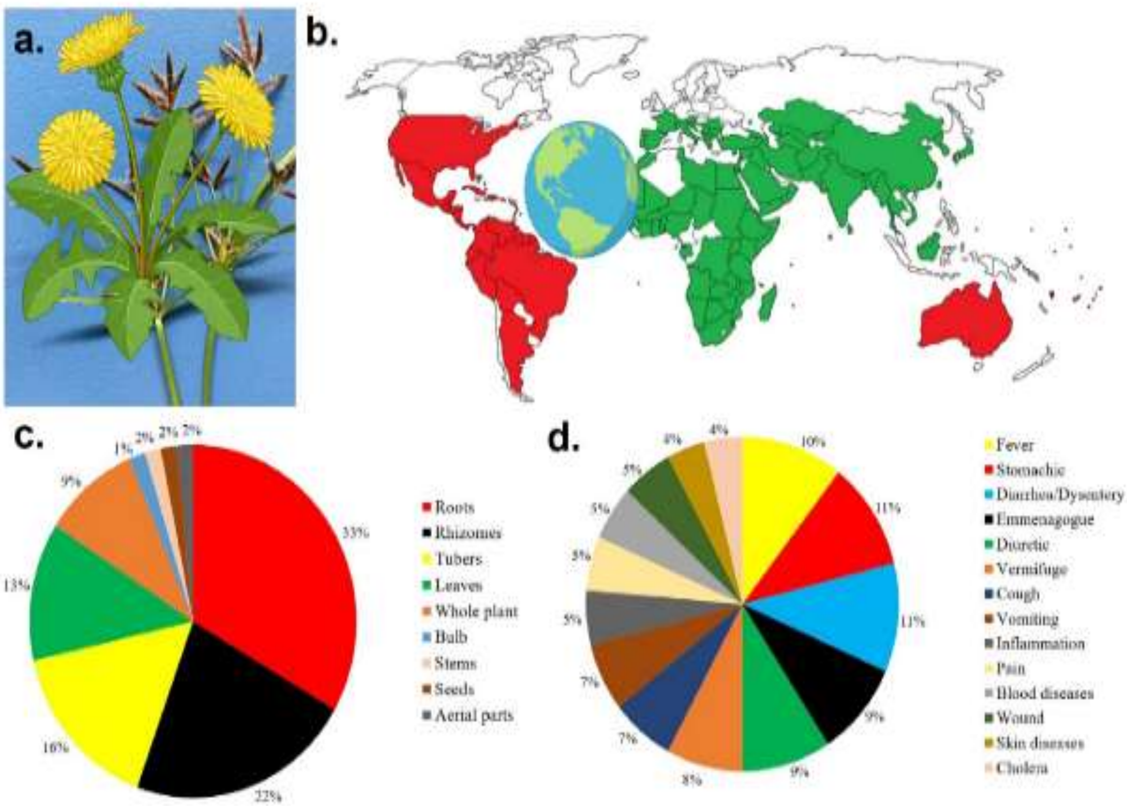

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Figure 2: Illustrates various aspects of Cyperus rotundus, a plant from the Cyperaceae family.

The figure includes the following components:a) Inflorescence: This image depicts the inflorescence of Cyperus rotundus, showcasing the arrangement and structure of its flowers.b) Worldwide distribution: This section provides a visual representation of the global distribution of Cyperus rotundus, highlighting the regions where the plant is found.c) Organs used in traditional preparations: This part of the figure displays the specific plant organs, such as roots, rhizomes, leaves, or other parts, that are commonly used in traditional preparations and remedies.d) Traditional medicinal applications: In this section, the figure presents the diverse range of traditional medicinal applications associated with Cyperus rotundus, including its use in treating various ailments and health conditions.

The ethno pharmacological benefits associated with invasive plants have gained support from a diverse range of findings obtained through in vitro and in vivo research. For instance, studies have reported on the pharmacological potential of several invasive plants in South Africa, including Cardiospermum grandiflorum, Chromolaena odorata, Dolichandra unguis-cati, and Gomphrena celosioides.Extracts derived from these plants have exhibited a broad spectrum of antibacterial activity against Escherichia coli, Klebsiella pneumoniae, and Enterococcus faecalis, with minimum inhibitory concentrations (MIC) ranging from 0.039 to 0.078 mg/mL. These results can be attributed to the presence of significant amounts of total phenolics, flavonoids, and tannins as phytochemicals within these plants. Moreover, it is noteworthy that none of the investigated extracts were found to be mutagenic, and they exhibited very low levels of cytotoxicity. Furthermore, researchers have isolated ten triterpenoids, including four newly discovered euphane-type compounds, from Lantana camara. In vivo experiments using a zebrafish model have demonstrated the therapeutic potential of these compounds as anti-inflammatory agents for the treatment of inflammatory diseases. These findings highlight the valuable pharmacological properties of invasive plants and their potential for developing novel therapeutic interventions. Through continued research and exploration, invasive plants can further contribute to the discovery of effective and safe treatments for various health conditions (Bezerra and Pinheiro 2022, Bezerra and Pinheiro 2022).

RESULTS AND DISCUSSION

Understanding the Extraction Methods and Chemical Composition of Invasive Plants

Extracting Phytochemicals from Invasive Plants

The various parts and tissues of invasive plants are known to contain a wide range of natural bioactive compounds, including polyphenols, flavonoids, reducing sugars, terpenoids, tannins, saponins, and proteins. These compounds play a significant role in the fabrication of bionanoparticles. To extract these valuable compounds from invasive plants, specific extraction methods are required. The extraction process typically involves several key stages, including solvent penetration into plant cells, dissolution of natural compounds in solvents, release of natural compounds from the plant material, and collection of the extracted compounds (Zhang et al. 2018).Several factors can influence the extraction yield, such as the type of solvents (considering polarity, selectivity, cost-effectiveness, and safety), the ratio of solvent to plant material, extraction process parameters (e.g., temperature, time, pH), and the particle size of the plant material. Fig. 3 illustrates several advanced techniques for extracting phytochemical compounds from invasive plants, including ultrasound-assisted extraction, microwave-assisted extraction, pulsed electric field processing, enzyme-assisted extraction, pressurized liquid extraction, and supercritical fluid extraction. These techniques represent state-of-the-art approaches that can enhance the efficiency of phytochemical extraction from invasive plants.The utilization of these advanced techniques for phytochemical extraction offers promising prospects for maximizing the yield and obtaining high-quality bioactive compounds from invasive plants (Nguyen, Van Tran et al. 2023).

Ultrasound-assisted extraction (UAE) is a commonly employed method for extracting phytochemicals from plant tissues. This technique utilizes high-frequency sound waves ranging from 20 kHz to 100 MHz to induce cavitation. Cavitation refers to the formation, growth, and collapse of tiny bubbles in the extraction medium.During UAE, the high-energy conditions created by cavitation promote the penetration of solvent molecules into plant cells. This facilitates the breakdown of cell membranes, allowing for the leaching and extraction of natural compounds from the solid plant material. The intense physical forces generated by the collapse of the bubbles enhance the mass transfer and release of phytochemicals into the solvent (Chemat, Rombaut et al. 2017). Reducing the particle size of the plant precursor is indeed beneficial in ultrasound-assisted extraction (UAE) for the extraction of phytochemicals from plants. Smaller particle sizes provide a larger surface area for contact with the solvent, promoting better penetration and extraction of the desired compounds (Vázquez-Rodríguez, Gutiérrez-Uribe et al. 2020)

Composition of Extracts from Invasive Plant Species

Like many plant species, invasive plants, such as the widely distributed Cissus quadrangularis vine in tropical and subtropical countries, contain a diverse array of phytochemicals. The aerial parts of this plant have been extensively studied and found to exhibit a rich composition of bioactive molecules. Notable phytochemicals identified in Cissus quadrangularis include Stilbene derivatives: These include compounds such as piceatannol, resveratrol, and quadrangularin-A, which are known for their antioxidant and anti-inflammatory properties. Flavonoids: Cissus quadrangularis extracts contain flavonoids such as daidzein, quercetin, and genistein. Flavonoids are known for their antioxidant, anti-inflammatory, and potential anticancer activities. Triterpenoids: The plant is also a source of triterpenoids like vitamin C (ascorbic acid) and friedelin. Triterpenoids are associated with various pharmacological properties, including anti-inflammatory and hepatoprotective effects (Henry, Mohanraj et al. 2016).

The presence of these constituents in Cissus quadrangularis extracts plays a significant role in providing antioxidant and stabilizing characteristics, which contribute to the medicinal applications of this plant species. In traditional medicine practices, C. quadrangularis has been widely used in India for the treatment of various health conditions, including General inflammatory conditions, Osteoporosis, Piles (hemorrhoids),Chronic ulcers and menstrual disorders (Phromnoi, Yodkeeree et al. 2022). In addition to the commonly found phytochemicals such as alkaloids, fatty acids, flavonoids, phenolic compounds, quinones, and terpenoids, invasive plants can possess additional allelopathic compounds because of their invasive properties. These compounds act as "bio herbicides," directly influencing or inhibiting the growth and reproduction of native plant species. For instance, mimosine (leucenol), a toxic non-protein allelochemical, has been identified in Leucaena leucocephala, a significant invasive species in several countries in Africa and Asia. Mimosine exhibits allelopathic activity, affecting the germination, growth, and development of neighboring plants. It acts as a growth inhibitor by interfering with protein synthesis and inducing oxidative stress in susceptible plant species, effectively suppressing their growth and survival. The presence of allelopathic compounds in invasive plants contributes to their competitive advantage and successful colonization of new habitats. These compounds can significantly impact native plant communities by reducing their biodiversity and altering ecosystem dynamics. Understanding the allelopathic potential of invasive plants and their specific allelochemicals is crucial in managing and mitigating the negative ecological impacts caused by invasive species (Kato-Noguchi and Kurniadie 2022).

Utilizing natural compounds from extracts of invasive plants, the green synthesis of nanoparticles is achieved in an environmentally friendly manner

Invasive plant extract enables the green synthesis of bionanoparticles

Two major approaches top-down and bottom-up, are commonly used to fabricate nanoparticles. The top-down approach involves reducing bulk materials into smaller nanoparticles, while the bottom-up approach involves building nanoparticles from atoms or molecules. The top-down pathway requires a significant amount of mechanical energy, often leading to drawbacks such as inefficient energy utilization and the generation of secondary pollution. This approach involves physically breaking down larger materials into smaller particles, typically through grinding, milling, or etching techniques. While it allows for control over nanoparticle size and shape, it may result in non-uniform size distribution and the loss of desired properties.On the other hand, the bottom-up pathway offers an alternative method for obtaining nanoparticles. In this approach, nanoparticles are synthesized or assembled by controlling the formation mechanism of building blocks at the atomic or molecular level. It involves chemical synthesis, self-assembly, or biological methods. By carefully manipulating the chemical reactions or utilizing self-assembly principles, nanoparticles with precise size, composition, and morphology can be achieved. This approach provides advantages such as better control over nanoparticle properties, scalability, and the ability to synthesize complex structures. The bottom-up pathway is particularly worth considering due to its ability to obtain nano-sized particles by controlling the formation mechanism of building blocks. It allows for the creation of nanoparticles from individual atoms or molecules, resulting in precise control over their characteristics. This approach is often employed in various fields, including nanotechnology, materials science, and medicine, to fabricate nanoparticles with tailored properties for specific applications (Rana, Yadav et al. 2020, Nguyen, Nguyen et al. 2022). Indeed, the extraction yield of bioactive compounds from plants can be influenced by various factors, including the choice of solvents, solvent-to-plant ratio, and operating extraction parameters. These factors play a crucial role in determining the efficiency and effectiveness of the extraction process. The selection of an appropriate solvent is essential for efficient extraction. Different solvents have varying polarities and abilities to dissolve specific compounds. Common solvents used in plant extraction include water, ethanol, methanol, acetone, and various organic solvents. The choice of solvent depends on the target compounds and their solubility characteristics. For example, polar compounds are often extracted using water or hydroalcoholic solvents, while non-polar compounds may require non-polar organic solvents. The ratio of solvent volume to the amount of plant material used is another crucial factor. The solvent-to-plant ratio affects the efficiency of compound extraction. A higher solvent-to-plant ratio provides better contact between the solvent and the plant material, facilitating the extraction process. However, excessively high ratios may lead to increased extraction of unwanted compounds or dilution of the target compounds. Various operating parameters can significantly impact the extraction yield. These parameters include extraction time, temperature, pressure, particle size, and agitation. Longer extraction times generally allow for more efficient extraction, but there is an optimal duration beyond which further extraction may not yield significant improvements. Temperature and pressure can enhance the extraction process by increasing the solubility of compounds or enhancing mass transfer. Particle size reduction can increase the surface area available for extraction, while agitation or stirring helps in improving the contact between the solvent and plant material (Bolade, Williams et al. 2020, Khan, Mubarak et al. 2020, Rana, Yadav et al. 2020).

The natural compounds derived from extracts of invasive plants play a pivotal role in the fabrication of bio nanoparticles.

Invasive plants harbor a variety of natural compounds that have the potential to serve as environmentally friendly, biocompatible, and clean reducing and capping agents. Extracts from these plants contain alkaloids, polyphenols, terpenoids, and polysaccharides, among other compounds, which can be utilized as alternatives to highly toxic chemicals in the green synthesis of bio nanoparticles. For example it is reported that utilized microwave-assisted water leaf extract from Parthenium hysterophorus to synthesize titanium dioxide nanoparticles (TiO2 nanoparticles). The fabricated nano materials were analyzed using FTIR spectroscopy, which confirmed the presence of functional groups such as alcohol, aromatic, aliphatic, and phenol groups. The hypothesis put forth was that these bioactive compound groups present in the extract of P. hysterophorus could interact with TiO4 salts and facilitate their reduction into TiO2 nanoparticles (Thandapani, Kathiravan et al. 2018).Similarly, In another study, TiO2 nanoparticles were synthesized using Acalypha indica, a medicinal weed known for its various therapeutic properties. The researchers highlighted the significance of functional groups, specifically hydroxyl and carbonyl groups, present in the plant extract. These functional groups were considered crucial in serving as the foundation for the fabrication of bio nanoparticles (Chinnathambi, Vasantharaj et al. 2021).Basically, Nanoparticles biosynthesized from different invasive plants can demonstrate diverse characteristics and biomedical activities. This hypothesis can be attributed to the significant variations in the type, concentration, and ratio of natural compounds and phytochemicals present in various invasive plant extracts. These variations in the composition of plant extracts can influence the properties and potential applications of the resulting nanoparticles (El-Gendy and Nassar 2021).

Moreover, employing invasive plant extracts for nanomaterial fabrication at ambient pressure and temperature helps reduce experimental and environmental risks. Interestingly, plant-derived capping agents mimic the properties of surfactants, effectively preventing the aggregation of bio nanoparticles and influencing their sizes and shapes. Additionally, the phytochemicals can be easily separated, avoiding the formation of any undesired layers on the surfaces of bionanoparticles and thereby enhancing their overall effectiveness (Choudhary, Kataria et al. 2017).

Invasive species	Plant part	NPs	Size (nm)	Shape	Responsible phytochemicals	References
Cassia fistula	Leaf	ZnO	5–15	Hexagonal	Polyphenols and flavonoids	(Suresh, Nethravathi et al. 2015)
Taraxacum officinale	Leaf	Co	50–100	Spherical	Carboxylic and hydroxyl groups in phenolic compounds	(Rasheed, Nabeel et al. 2019)
Solanum nigrum	Leaf	ZnO	49	Spherical	Flavonoids, alkaloids and phenolic compounds	(Muthuvel, Jothibas et al. 2020)
Parthenium hysterophorus	Leaf	Ag	10	Spherical	Flavonoids, alkaloids, car bohydrates and proteins	(Sivakumar, Surendar et al. 2021)
Parthenium hysterophorus	Leaf	TiO_2	20–50	Spherical	Alcohols, phenols, al kanes, and fluoroalkanes	(Thandapani, Kathiravan et al. 2018)
Borassus flabellifer	Fruit	Au	5–7	Spherical	Ascorbic acid, alkaloids, calcium, protein, reducing and non-reducing sugars	(Vandarkuzhali, Karthikeyan et al. 2021)
Ziziphus jujuba	Fruit	ZnO	29	Spherical	Flavonoids such as rutin, and quercetin	(Golmohammadi, Honarmand et al. 2020)
Ziziphus jujuba	Leaf	ZnO	15	Spherical	phenols, alcohols, carbohydrate	(Alharthi et al. 2021)
Alternanthera sessilis	Leaf	Ag	20–30	Multi shapes	Tannins, carbohydrates, proteins, ascorbic acid	(Niraimathi et al. 2013)
Cassia occidentalis	Leaf	Cu	26	Spherical and oval	Phenolic compounds including aloe-emodin, apigenin, emodin, rhein, and vitexin	(Gondwal and Joshi nee Pant 2018)
Convolvulus arvensis	Leaf	Ag	28	Spherical	Flavonoids, phenols, aliphatic amines and organic acids	
Foeniculum vulgare	Stem	V_2O_5-Fe_2O_3	90	Semi-spherical	Alkaloids and polyphenols	(Yulizar, Apriandanu et al. 2021)
Foeniculum vulgare	Seed	Au	20	Spherical	Polyphenols and flavonoids (including chlorogenic acid, rosmarinic acid, apigenin and quercetin)	(Choudhary, Kataria et al. 2017)
Euphorbia maculata	Aerial parts	CuO	18	Spherical	Phenols and alcohols	(Pakzad, Alinezhad et al. 2019)
Catharanthus roseus	Leaf	Pd	38	Spherical	Phenolic compounds	(Kalaiselvi, Roopan et al. 2015)
Catharanthus roseus	Whole plant	Co	27	Spherical	Terpenoid indole alkaloids, tannins, flavanoids,	(Zaib, Shahzadi et al. 2020)

					polyphenols and carbohydrates	
Catharanthus roseus	Flower	Ag	30	Spherical	Terpenoids, Steroids, Proteins, carbohydrate, tannins and saponins	(Kandiah and Chandrasekaran, 2021)
Arctium lappa	Root	Au	24	multi shapes	polyphenol, steroids, terpenoids, glucides, and proteins	(Nguyen et al. 2018)
Apium graveolens	Stem	Au	22	multi shapes	Ascorbic acid, amines, phenols, alkaloids and favonoids	(Khoshnamvand et al. 2020)
Mimosa pudica	Root	Fe_3O_4	67	Spherical	Mimosine (β-3-hydroxy-4 pyridone amino acid)	(Niraimathee et al. 2016)
Centaurea cyanus	Whole plant	Fe_2O_3	24	Spherical	Flavonoid and phenolic compounds	(Davarnejad et al. 2020)
Carpobrotus acinaciformis	Flower and leaf	Ag/TiO_2	20–50	Spherical	Flavonoids and phenols including neohesperidin, rutin, catechin, hyperoside, and ferulic acid	(Rostami-Vartooni et al. 2016)
Sphagneticola trilobata	Root	ZnO	65–80	Irregular	Tannins, polyphenols, and flavonoids	(Shaik et al. 2020)
Kyllinga brevifolia	Whole plant	Ag	10–30	Quasi-spherical	Protein, carbohydrate, and plant sterols (campesterol and stigmasterol	(Isa and Lockman, 2019)
Trifolium pratense	Flower	ZnO	60–70	Not reported	Anthocyanins, phenolic acids	(Dobrucka and Długaszewska, 2016)
Peltophorum pterocarpum	Flower	ZnO	69	Spherical	Phenolic compounds, saponins, flavonoids, steroids, xanthoproteins, tannins, coumarins, carboxylic acids, and carbohydrates	(Dobrucka and Długaszewska 2016)

The provided table (Table 1) presents a comprehensive analysis of several invasive plant species, focusing on their plant parts, the types of nanoparticles (NPs) used in the analysis, NP size range, NP shape, and the responsible phytochemicals found within each species. The table highlights key information necessary to understand the impact of invasive species on native plants and their associated ecosystems. Each row in the table represents a specific invasive plant species and provides details such as the plant part analyzed (e.g., leaves or fruits), the type of NP used in the analysis (e.g., ZnO, Co, Ag, TiO2, or Au), the size range of the NPs in nanometers (nm), the shape of the NPs (e.g., hexagonal or spherical), and the phytochemicals identified as being responsible for various biological activities.

CONCLUSION

The present review critically evaluated the positive and negative aspects of invasive plants and explored new avenues for utilizing bioactive compounds derived from these plants as natural reducing and capping agents for environmentally friendly bio nanoparticle synthesis. The invasive plants were found to contain various bioactive molecules, including stilbene derivatives like piceatannol, resveratrol, and quadrangularin-A, as well as flavonoids and tri-terpenoids. These compounds significantly influenced the formation, characterization, and biomedical properties of nanoparticles such as silver (Ag), gold (Au), zinc oxide (ZnO), and copper oxide (CuO). Bio nanoparticles produced using invasive plant extracts exhibited remarkable antibacterial and antifungal activities, making them promising therapeutics against infectious diseases. Additionally, many of these bio nanoparticles showed potential as anticancer agents and antioxidants. The review also addressed the mechanisms underlying the biomedical activities of bio nanoparticles synthesized using invasive plants. In summary, harnessing the potential of invasive species for bio nanoparticle fabrication can help mitigate their negative effects and economic losses. Furthermore, it is anticipated that bio nanoparticles synthesized using invasive plant extracts will open up new frontiers in biomedical applications, therapeutic treatments, and smart agriculture.

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