

From Invasive Aquatic Weed to Medicinal Resource: A Narrative Review of the Phytochemical Profile and Therapeutic Potential of *Pontederia crassipes*

Dinesh Kumar D¹, Chandra Philip X¹, Sundarapandian S², Balaji Karunakaran^{3*} and Madhan Krishnan^{4*}

¹Department of Anatomy, Mahatma Gandhi Medical College and Research Institute Pondicherry India, Sri Balaji Vidyapeeth (Sbv), Puducherry 607403, India

²Department of Anatomy, SRM Institute of Science and Technology, Kattankulathur-603203, Tamil Nadu, India

³Department of Anatomy, Saveetha Medical College & Hospital, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 602105, Tamil Nadu, India

⁴Assistant Professor, Faculty of Research, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam-603103, Tamilnadu, India

¹drdineshkumaranat@gmail.com ; chandraphilipx@mgmcri.ac.in, ²sssspandian@gmail.com

³mevsig@gmail.com and ⁴drmadhan@care.edu.in; kmadhan91@gmail.com

*Corresponding Author: Dr. Balaji Karunakaran Ph. D/mevsig@gmail.com

Dr. Madhan Krishnan M.Sc., Ph. D/drmadhan@care.edu.in; kmadhan91@gmail.com

Received: 14th June, 2026; Revised: 20th July 2026; Accepted: 20th August, 2026; Available Online: 05th September 2026

ABSTRACT

Pontederia crassipes (Mart.) Solms, often referred to as water hyacinth, is known as one of the most widely spread invasive aquatic plants that has a long history of negative ecological and economic consequences. Nevertheless, new scientific evidence shows that this species has a significant potential for medical and biotechnological applications due to its diverse phytochemical content. The present narrative review examines the botanical characteristics, ecological role, phytochemical composition, literature on pharmacological properties, safety issues of *P. crassipes*, and its potential therapeutic applications. A systematic literature examination was conducted by using PubMed and Google Scholar search engines to find published studies on the biological properties of the plant. The literature shows that *P. crassipes* contains a wide variety of active components including phenolics, flavonoids, phosphosides, triterpenoids, and quinone derivatives that allow it to manifest antioxidant, antibacterial, anti-inflammatory, cytoprotective, and protective effects. Moreover, this species displays impressive phytoremediation abilities and exciting possibilities in nanotechnology along with environmental stewardship and circular economy. Regardless of the great findings, most studies focus only on applications of phytochemistry, vitro assays and computational research, while very few of them are concerned with in vivo or clinical trials. Nevertheless, *P. crassipes* is a promising but underestimated medicinal plant indeed. More studies must focus on toxicological evaluations, mechanisms of action and translational research of this species to prove the medicinal properties of *P. crassipes*.

Keywords: *Pontederia crassipes*, water hyacinth, phytochemistry, medicinal plants, antioxidant activity, antimicrobial activity, therapeutic potential.

How to cite this article: Kumar DD, Philip X, Sundarapandian S, Karunakaran B, Krishnan M., From Invasive Aquatic Weed to Medicinal Resource: A Narrative Review of the Phytochemical Profile and Therapeutic Potential of *Pontederia crassipes* Int J Drug Deliv Technol. 2026; 16(7): 2161-2172. DOI: 10.25258/ijddt.16.7.221

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Medicinal plants have retained their significance in both healthcare and drug development, even though synthetic drugs have progressed remarkably. The World Health Organization (WHO) has disclosed that almost 80% of the world's populace uses conventional plant medicine for its healthcare requirements. In the meantime, the rising frequency of chronic diseases, the pollution of the environment, resistance to antimicrobials, and the diseases induced by toxins have led to the increased effort in the search for new bioactive compounds derived from nature. The latest literature states that medicinal plants continue to

be an important source of different phytochemicals acting as antioxidants, anti-inflammatory, antimicrobial, immunomodulatory, and cytoprotective [1, 2]. In this regard, there is interest in alternative and underexploited plant species which have generally been ignored, either due to their ecological or economic significance [3]. One of such species is *Pontederia crassipes* (Mart.) Solms, previously known as *Eichhornia crassipes* or water hyacinth. Recognized as one of the most aggressive aquatic invasive species, *P. crassipes* has spread through fresh waters around the world causing serious ecological and socioeconomic problems [4-6]. Thanks to its rapid growth,

*Author for Correspondence: mevsig@gmail.com

vegetative reproduction, and high adaptability, the species has managed to colonize regions outside its native places in South America [7, 8]. As a consequence, water hyacinth management has been mostly concentrating on containment and eradication methods to minimize its impact on biodiversity, fisheries, irrigation systems, transport systems, and water quality [9, 10].

The biological characteristics that predispose this species to invasion pave the way for scientific explorations related to its possibility as a renewable source of bioresources. Over the past ten years, there has been an increasing amount of information which proved that the reputation of *P. crassipes* as an environmental trouble was not entirely accurate. Biochemical analysis of the plant biomass proved its efficiency in those processes as wastewater treatment, biofuels production, agriculture, nano industry and bioproduct development [11-13]. Recent studies in the field of phytochemistry have provided evidence for a wide range of secondary metabolites found in the plant, such as phenolic compounds, alkaloids, flavonoids, sterols, quinones and terpenoids, some of which are already recognized for their pharmacological activity [14]. The therapeutic potential of *P. crassipes* can be seen as part of a greater scientific movement towards studying the potential of underutilized plants for the purpose of obtaining new medicines. Environmental conditions stimulate the production of secondary metabolites essential for plant survival, their compounds often being biologically active substances useful for treatment purposes [15, 16]. It has been proven through recent studies that the extract of *P. crassipes* possesses several properties ranging from the antioxidant properties to that of enzyme modulating capabilities which indicates that these extracts can be looked at as a potential remedy in the treatment and prevention of the diseases owing to or related to oxidative stress conditions. However, the studies that are available are fragmented in nature with plenty of information on the isolated biological action of the *P. crassipes*, or environmental practices, or phytochemical properties and development in isolating them into one significant area of pharmacological action has not been considered. Thus, a review of the latest information in the area is necessary. Thus, the objective of the review is to focus on the properties of the *P. crassipes* phytochemical and its activities.

Search Strategy and Literature Selection

The present narrative review was conducted to critically evaluate the current evidence regarding the phytochemical profile, biological activities, and therapeutic potential of *Pontederia crassipes* (Mart.) Solms, with particular emphasis on its transformation from an invasive aquatic weed to a potential medicinal resource. A structured literature search was performed between January and June 2026 using the electronic databases PubMed (<https://pubmed.ncbi.nlm.nih.gov/>) and Google Scholar (<https://scholar.google.com/>), which served as the primary sources of scientific information. The search strategy was designed to identify peer-reviewed studies investigating the

botanical characteristics, phytochemistry, pharmacological activities, medicinal applications, toxicological properties, environmental significance, and biotechnological utilization of *P. crassipes*.

The keywords and combinations of keywords that appeared in the titles, abstracts, and, when applicable, the medical subject headings (MeSH) included the following combinations of keywords: even though either *Pontederia crassipes* or *Eichhornia crassipes* or the phrase "water hyacinth" were searched for in the title, abstract, where applicable, and medical subject headings (MeSH) provided.

OR flavonoid* OR sterol* OR alkaloid* OR triterpenoid*) AND (pharmacological activity* OR biological activity* OR antioxidant OR anti-inflammatory OR antimicrobial OR hepatoprotective OR respiratory protective OR cytoprotective OR therapeutic potential OR medicinal plant*). Additional searches included combinations of the following terms: (*Pontederia crassipes* OR water hyacinth) AND (invasive species OR aquatic weed OR ethnomedicine OR ethnobotany OR phytoremediation OR toxicology OR medicinal application OR natural product*). Boolean operators (AND, OR) and database-specific filters were used to refine search results. Articles published in English were considered. The review included original research articles, systematic reviews, narrative reviews, short communications, and book chapters providing scientific information on phytochemistry, pharmacological properties, biological activities, ethnomedicinal importance, environmental aspects, and potential for therapeutic applications of *P. crassipes*.

Studies that involved unpublished reports, conference abstracts that lacked full-text, and non-English reports were left out. Same goes for duplicate entries, or articles that do not provide enough scientific data relevant to the aim of this review. Articles published in the last decade in peer-reviewed journals were searched for, however, older crucial articles were also included when deemed worthwhile. To cover all relevant literature, the reference lists of the articles were screened to find additional publications not found via the literature databases. The study focused on the phytochemical composition of *P. crassipes* and its antioxidants and anti-inflammatory properties, antimicrobial effects, possible liver protectiveness, and respiratory problems, as well as emerging biomedical use of these substances. Although the search process followed a structured approach, final article selection was based on scientific relevance, methodological quality, originality of findings, and contribution to the understanding of *P. crassipes* as a potential medicinal resource. This approach enabled the inclusion of both foundational and contemporary evidence while maintaining the narrative nature of the review.

Botanical and Ecological Overview of *Pontederia crassipes*

Previously known as *Eichhornia crassipes* and called water hyacinth, the plant *Pontederia crassipes* (Mart.) Solms belongs to the family Pontederiaceae and is free-floating

flora. It is native to the Amazon basin located in South America but has become one of the most widespread invasive plants across the globe due to its fast growth, adaptability, and reproductive potential. The plant has a specific morphological structure with glossy, ovate leaves, a swollen petiole that serves the purpose of buoyancy, fibrous roots, and beautiful purple flowers on spikes (see Figure 1 for details). All of these features help the species survive in different freshwaters and make it invasive. The

plant reproduces sexually through seeds, but the most important means of propagation for it is vegetative reproduction with the aid of stolons, which allows for rapid colonization and biomass development. Favorable conditions can make the formation of dense floating mats happen [17, 18]. Its distribution now extends across Africa, Asia, North and South America, and Oceania, where nutrient enrichment, eutrophication, and climate change have facilitated establishment and expansion [8, 18].



Figure 1: *Pontederia crassipes* (water hyacinth)

The ecological impact of *P. crassipes* on freshwater ecosystems is considerable. Heavy infestations can lead to reduced light penetration and dissolved oxygen, interrupted nutrient cycle, and reduced number of native aquatic plants, thereby affecting biodiversity and ecosystem functioning [10]. Also, it adversely affects fisheries, irrigation systems, navigation, and hydropower, bringing serious socio-economic implications. However, recent studies show the potential of the plant as a useful biological resource [19]. Its deep root system is an effective phytoremediator, which can help eliminate heavy metals and pollutants from contaminated waters. Furthermore, bioenergy production, biomaterials usage, and medical application are all examples of sustainable methods of utilization of the plant that have recently gain popularity. Thus, modern studies consider *P. crassipes* not only land invasive weed but also a prospective environmental and biomedical resource.

Phytochemical Constituents and Bioactive Compounds of *Pontederia crassipes*

The growing interest in *Pontederia crassipes* as a medicinal resource is largely attributable to its diverse phytochemical composition. Recent investigations have demonstrated that this aquatic macrophyte contains a broad spectrum of secondary metabolites with potential pharmacological significance. Although earlier studies primarily focused on its ecological and phytoremediation properties, contemporary research has increasingly emphasized the identification and characterization of bioactive compounds responsible for its biological activities.

Phenolic Compounds and Flavonoids

Phenolic compounds and flavonoids are among the most researched natural compounds in the *P. crassipes* (Figure 2). These compounds are known for their antioxidant, anti-inflammatory, and cytoprotective abilities. Misra, Dutta and

Ray [20] proved that biochemical composition of *P. crassipes* is changable according to environmental conditions, and this means that the amount of created phenolic compounds can change depending on

physiological and ecological conditions. This fact is essential, since environmental stress promotes the increase of secondary metabolite synthesis.

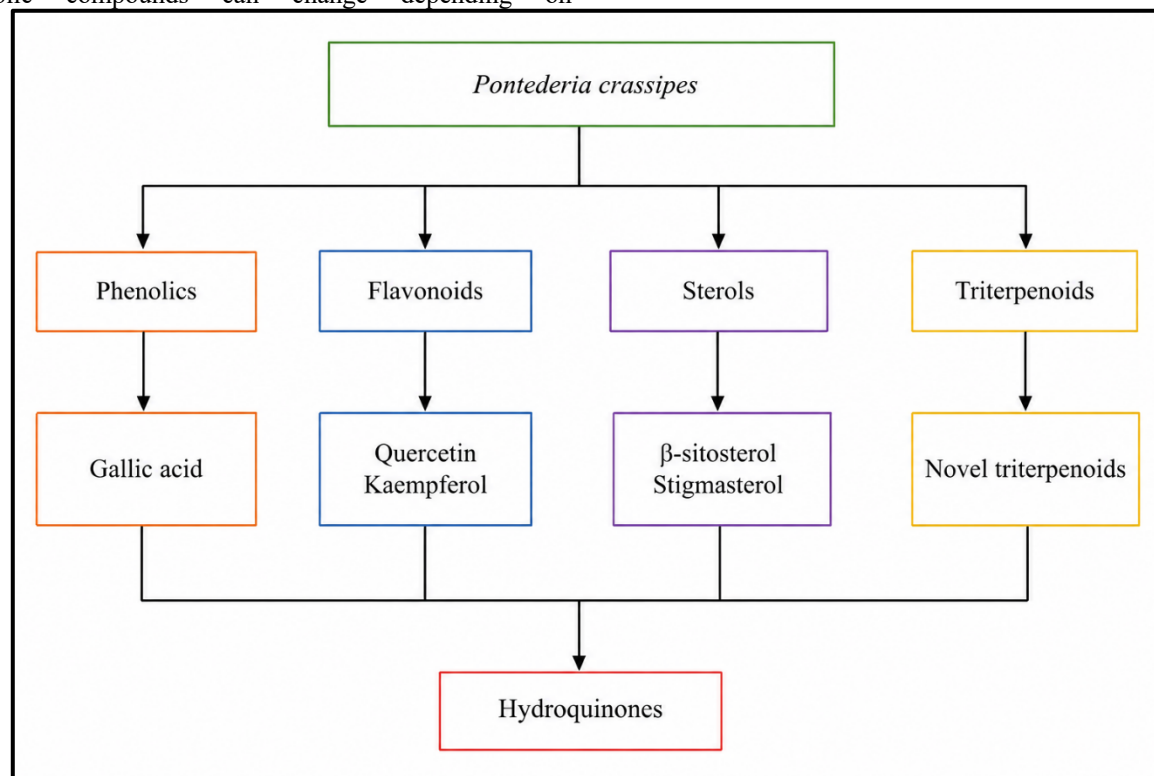


Figure 2: Major phytochemical classes and representative bioactive compounds reported in *Pontederia crassipes*. The plant is rich in phenolics, flavonoids, phytosterols, triterpenoids, and hydroquinone derivatives, which collectively contribute to its diverse pharmacological activities.

The thorough examination of the phytochemistry conducted by Bakrim et al. [21] confirmed the presence of phenolic compounds and flavonoids in the aerial parts of *P. crassipes*. Through advanced phytochemical profiling techniques, it was established that many compounds with antioxidant activities were present in the specimen and that the plant showed considerable free-radical scavenging effects. The analyses of molecular docking indicated the ability of several phytochemicals to interact well with targets associated with oxidative stress and inflammation. The authors concluded that the biological activities of the extract are related to the interaction of many phytochemicals and not only the activity of one phytochemical. This statement complies with the concept according to which extracts of whole plants are more effective than isolated phytochemicals thanks to the additive or synergistic properties of the compounds contained in the extracts. In summary, the studies have shown that phenolics and flavonoids are important contributors to the antioxidant capacity of the studied plant. However, the existing information regarding quantitatively different phytochemicals in different geographical populations and extraction methods is not enough for making sufficient conclusions.

Triterpenoids

Triterpenoids are another one of the significant chemical types of bioactive compounds discovered in *P. crassipes*. Triterpenoids are known to exhibit anti-inflammatory, antiviral, antioxidant, hepatoprotective, and immunomodulatory activities in medicinal herbs. According to Adeloye et al. [22], two new tetracyclic triterpenoid compound combinations were isolated and studied from *P. crassipes*. This research has shown that these substances are capable of effective molecular interactions with biological targets during anti-HIV virtual screening process. Though computational predictions are not the substitutes for biological verification, identification of one-of-a-kind triterpenoids represents advancement in knowledge about the chemistry of *P. crassipes*. The presence of new triterpenoids is extremely important because the pentacyclic triterpenoids of other medicinal plants demonstrated antioxidant and organ-protecting features. Thus, it may be assumed that the identified new substances could increase the medical value of *P. crassipes* together with their pharmacological potential.

Hydroquinones and Related Quinone Compounds

Quinone derivatives are well known for their antioxidant, antimicrobial and redox-modulating features. Recent studies have indicated that *P. crassipes* is possibly a rich source of bioactive quinones with relevant medical potential. Kandulo [23] succeeded in isolating

hydroquinone-based fractions from *P. crassipes* to check their efficacy against some veterinary bacterial diseases. The study found that the fractions had a measurable effect and revealed promising interactions of hydroquinones with the bacteria. These data indicate that the presence of quinones contributes considerably to the antimicrobial activity of the plant. Nonetheless, it should be pointed out that hydroquinones may possess some toxic properties that are not dependent on hydroquinone concentration.

Phytosterols

A major breakthrough in phytochemistry related to *P. crassipes* is the description of its sterol fraction. The phytosterols are known to have anti-inflammatory, anti-oxidative, membrane-stabilizing, and immunomodulatory properties. Ben Bakrim et al. [24] used GC-MS methodology to profile the total sterol extracts of *P. crassipes* from Lake Tana, Ethiopia, and verified different phytosterols with specific biological activities with the help of molecular docking. It was shown that the identified sterols had good interaction with those targets responsible for the regulation of oxidative stress and inflammatory processes. The obtained results are of extraordinary importance since sterols are known to possess hepatoprotective and respiratory protective properties in various medicinal plants.

Bioactive Metabolites Associated with Antimicrobial Activity

P. crassipes seems to exert its antimicrobial attributes through the synergistic action of several groups of secondary metabolites rather than the effect of a single active substance. Kandulo [22] found that antibacterial action could partially be the result of hydroquinone-containing fractions, while Bakrim et al. [21] pointed out that the identified phenolic and flavonoid compounds were responsible for the antimicrobial activity due to the involvement of oxidative stress and disruption of membranes. Moreover, Semu et al. [25] provided complementary evidence through their experiments on *P. crassipes* extracts applied to silver nanoparticles synthesis. The synthesis of biologically active nanoparticles confirms the presence of phytochemicals possessing reducing and stabilizing properties which help to produce nanoparticles. The nanoparticles acquired in the process displayed efficacy against multidrug resistance pathogens, thus proving the significance of the metabolites synthesized from *P. crassipes*. The use of silver nanoparticles cannot be attributed solely to *P. crassipes* extract, but the attainment

of the results indicates that there may be various applications of *P. crassipes* compounds in medicine.

Phytochemicals Associated with Nematicidal Activity

Recent studies have broadened the array of biological activities concerning phytochemicals derived from *P. crassipes* beyond the scope of the traditional applications of pharmacology. Rabbani et al. [26] examined the nematicidal effect of leaf extracts against *Meloidogyne javanica* using various methods such as in vitro tests, greenhouse tests, phytochemical experiments and molecular docking analysis. The study yielded several phytochemical substances that might be responsible for the ability of nematodes to grow and survive. Although the study is mainly significant in agriculture, it confirms that the metabolites of *P. crassipes* possess diverse biological activities. Moreover, a study supports the notion that the plant contains many active compounds that can act on many biological targets which prove its potential as a source of new substances for therapy.

The research suggests that *Pontederia crassipes* has a wide range of chemically different bioactive ingredients which include flavonoids, phenolic compounds, biogenic acetyl triethanolamine, and other secondary elements. The studies show that phenolic and flavonoids are the main contributors in the antioxidant activity whereas triterpenoids and sterols play an important role in anti-inflammatory activity and cytoprotection mechanisms. Hydroquinones and its derivatives contribute to antimicrobial activity [27, 28]

Therapeutic Potential of *Pontederia crassipes*

The therapeutic potential of *Pontederia crassipes* (Mart.) Solms is gaining importance in recent years. Previously considered a troublesome invasive aquatic plant, the species is increasingly recognised as a source of bioactive compounds which could be applied in pharmaceutical, biomedical and nutraceutical fields (table 1). This shift from an environmental nuisance to a medicinal source is explained by progress made in phytochemical profiling and biological activity screening, which detected that the plant contains diverse secondary metabolites that can influence different biological pathways [29, 21]. At the moment, it is believed that the medicinal value of *P. crassipes* is connected with its antioxidant, antimicrobial, anti-inflammatory, cytoprotective and detoxifying properties (figure 3), but the degree of scientific substantiation differs from one activity to another.

Table 1: Summary of Therapeutic and Biological Activities of *Pontederia crassipes*

S. No.	Therapeutic Activity	Animal Model / Cell Line	Disease Model / Experimental Model	Reference
Antioxidant Activity				
1	Antioxidant activity of aerial part extracts	Cell-free antioxidant systems	Oxidative stress/free radical scavenging model	[21]
2	Antioxidant potential associated with phytochemical constituents	In silico molecular targets	Oxidative stress-related molecular pathways	[24]
Antimicrobial Activity				

3	Antibacterial activity of hydroquinone-containing isolates	Veterinary bacterial isolates	Bacterial infection model	[23]
4	Antibacterial activity against multidrug-resistant bacteria	MDR bacterial strains	Antimicrobial screening model	[30]
5	Antimicrobial activity of biosynthesized silver nanoparticles	Multidrug-resistant microbes	Antimicrobial model	[25]
6	Antimicrobial activity of related <i>Pontederia</i> species extracts	Bacterial strains	Antibacterial model	[31]
Anti-inflammatory Activity				
7	Anti-inflammatory potential predicted by molecular docking	In silico protein targets	Inflammation-related signaling pathways	[21]
8	Anti-inflammatory activity of sterol-rich extract	In silico molecular targets	Inflammatory pathway modulation	[24]
Cytoprotective Activity				
9	Cytoprotective effects associated with phenolics and flavonoids	In vitro and in silico models	Cellular oxidative injury model	[21]
10	Cell-protective activity of phytosterol fraction	In silico models	Oxidative stress and membrane protection	[24]
Antiviral Activity				
11	Anti-HIV potential of novel triterpenoid conjugates	In silico HIV targets	HIV molecular docking model	[22]
Nematicidal Activity				
12	Nematicidal activity of leaf extract	<i>Meloidogyne javanica</i>	Root-knot nematode infestation model	[26]
Phytoremediation / Environmental Detoxification				
13	Heavy metal remediation capacity	Aquatic plant model	Heavy metal-contaminated water systems	[19]
14	Pollutant removal and wastewater treatment	Aquatic ecosystems	Wastewater remediation model	[29]
Biotechnological / Nanomedicine Applications				
15	Green synthesis of silver nanoparticles	AgNP formulation	Nanobiotechnology and antimicrobial application	[25]
16	Biomass valorization for pharmaceutical and biomedical applications	Biomass utilization studies	Circular bioeconomy model	[13]

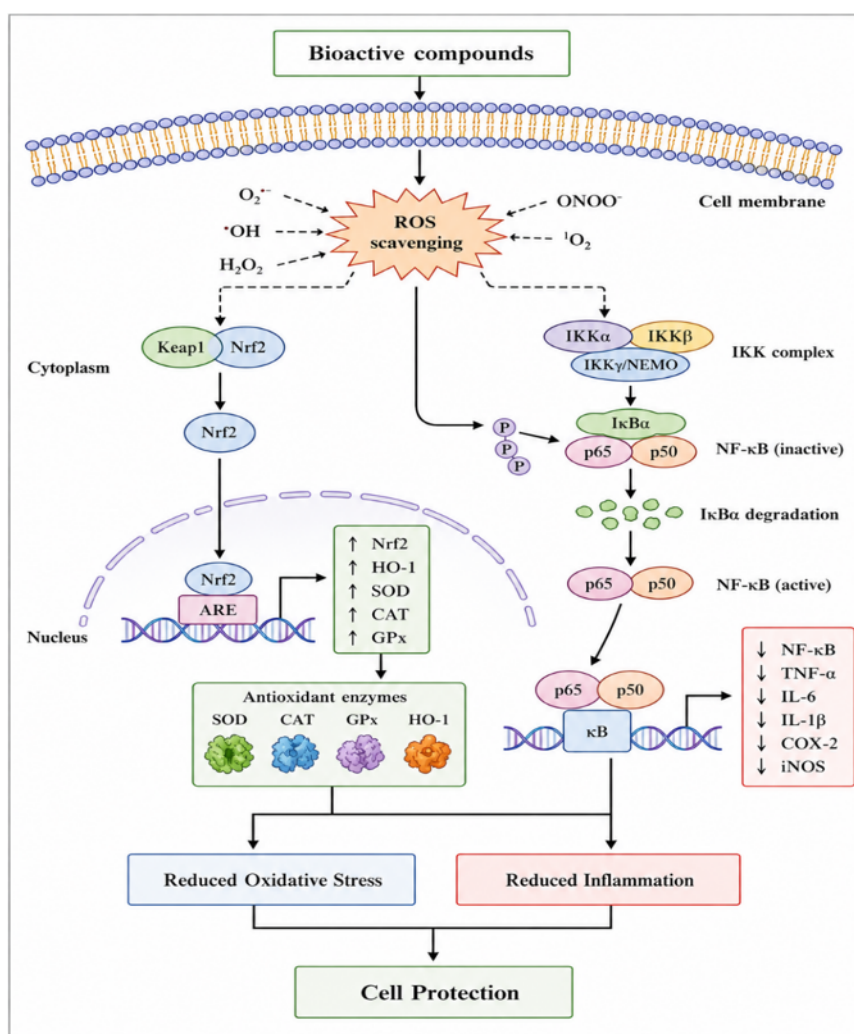


Figure 3: Molecular signaling pathways mediating the therapeutic effects of *Pontederia crassipes* bioactive compounds. Bioactive phytochemicals activate the Nrf2/ARE antioxidant pathway and inhibit NF-κB-mediated inflammatory signaling, resulting in increased antioxidant enzyme expression, suppression of pro-inflammatory mediators, reduced oxidative stress and inflammation, and enhanced cellular protection.

Antioxidant Potential

Among the various therapeutic properties attributed to *P. crassipes*, antioxidant activity is supported by the strongest body of evidence. Oxidative stress plays a central role in the pathogenesis of numerous chronic disorders, including respiratory diseases, liver injury, cardiovascular disorders, neurodegeneration, and metabolic dysfunction. Consequently, plants rich in antioxidant phytochemicals are increasingly investigated as potential therapeutic agents. Bakrim *et al.* [21] conducted one of the most comprehensive evaluations of *P. crassipes* aerial extracts and demonstrated substantial free-radical scavenging activity. Their phytochemical analysis revealed abundant phenolic compounds and flavonoids, which are widely recognized for their ability to neutralize reactive oxygen species and prevent oxidative damage to cellular macromolecules. Molecular docking analyses further suggested that several identified metabolites may interact with proteins involved in oxidative stress regulation. The findings of Bakrim *et al.* [21] are particularly significant because oxidative stress is a common pathogenic

mechanism underlying many diseases. However, most evidence currently derives from in vitro assays and computational studies. Although these approaches provide mechanistic insight, additional in vivo investigations are required to establish the clinical relevance of the observed antioxidant effects. The antioxidant potential of *P. crassipes* is further supported by studies demonstrating its ability to mediate the biosynthesis of biologically active silver nanoparticles, a process that relies heavily on the reducing properties of plant-derived antioxidant compounds [25]. Collectively, these observations indicate that antioxidant activity represents one of the principal therapeutic attributes of the species.

Antimicrobial Potential

The increasing prevalence of antimicrobial resistance has intensified the search for novel antimicrobial agents from natural sources. In this context, *P. crassipes* has attracted attention because of its ability to inhibit the growth of various microbial pathogens. Kandulo [23] investigated hydroquinone-containing fractions isolated from *P. crassipes* and demonstrated significant antibacterial activity

against selected veterinary pathogens. In addition to laboratory-based antimicrobial testing, molecular docking analyses revealed favorable interactions between isolated compounds and microbial targets, supporting their potential mechanism of action. A broader perspective was provided by Karunaratne *et al.* [30], who reviewed available evidence regarding the antibacterial activity of *P. crassipes* against multidrug-resistant microorganisms. The review concluded that the antimicrobial effects of the plant are likely mediated by multiple phytochemical classes acting synergistically to disrupt bacterial growth, membrane integrity, and metabolic processes. Importantly, the authors emphasized the need for standardization of extraction methods because variations in phytochemical composition may influence biological activity. Although not directly focused on *P. crassipes*, the study by Jagessar and Samaroo (2025) [31] on *Pontederia cordata* provides additional support for the antimicrobial potential of the genus. Similarities in phytochemical composition between species suggest that antimicrobial activity may represent a broader characteristic of the Pontederiaceae family. Further evidence comes from nanoparticle-based studies. Semu *et al.* [25] reported that silver nanoparticles synthesized using *P. crassipes* extracts exhibited substantial activity against multidrug-resistant microorganisms. While part of the antimicrobial effect is attributable to the nanoparticles themselves, the successful synthesis process underscores the biological activity of plant-derived metabolites.

Anti-Inflammatory Potential

Chronic inflammation contributes to the development and progression of numerous diseases, including respiratory disorders, liver diseases, autoimmune conditions, and metabolic syndromes. Consequently, natural compounds capable of modulating inflammatory pathways are of considerable therapeutic interest. Bakrim *et al.* [21] reported that several phytochemicals identified in *P. crassipes* demonstrated favorable interactions with inflammation-related molecular targets during docking analyses. The presence of phenolics, flavonoids, and triterpenoids suggests a capacity to regulate inflammatory mediators and oxidative stress-sensitive signaling pathways. Additional support for anti-inflammatory potential comes from the phytosterol-rich extracts characterized by Ben Bakrim *et al.* [24]. Their GC-MS profiling identified sterol compounds known to possess anti-inflammatory and membrane-stabilizing activities. Molecular docking studies further indicated interactions with proteins involved in inflammatory regulation. Although direct experimental studies examining anti-inflammatory effects in animal disease models remain limited, the cumulative phytochemical evidence strongly suggests that *P. crassipes* possesses significant anti-inflammatory potential.

Cytoprotective and Organ-Protective Potential

The ability of plant-derived compounds to protect tissues against oxidative and inflammatory injury has become an important focus of pharmacological research. Cytoprotective activity typically involves stabilization of

cellular membranes, preservation of mitochondrial function, modulation of redox homeostasis, and inhibition of apoptosis. The phytochemical composition of *P. crassipes* suggests substantial cytoprotective potential. Bakrim *et al.* [21] demonstrated that the plant contains compounds capable of targeting pathways associated with oxidative stress and cellular injury. Similarly, Ben Bakrim *et al.* [24] identified sterol constituents with biological activities relevant to cellular protection. From a toxicological perspective, these findings are particularly important because oxidative stress and inflammation are central mechanisms in chemically induced organ injury. Consequently, the phytochemical profile of *P. crassipes* provides a plausible mechanistic basis for potential hepatoprotective and respiratory protective effects.

Hepatoprotective Potential

Due to its important role in the metabolism of xenobiotics, the liver is highly vulnerable to oxidative and inflammatory injury. Although studies of *P. crassipes* in hepatotoxicity tests are rare at present, the presence of many phytochemicals in the plant confirms that the plant is potentially hepatoprotective. *P. crassipes* has several phytochemicals like phenols, flavonoids, phytosterols, and triterpenes that have already shown hepatoprotective abilities in other medicinal plants [21, 24]. The lack of direct hepatoprotective studies of the plant is a huge research gap. Since the phytochemicals in the plant are biologically active, researchers should perform experiments on *P. crassipes* to verify its ability to protect liver from injury.

Respiratory Protective Potential

Respiratory ailments can come with occurrences of oxidative stress, inflammatory response, damage of epithelial cells as well as tissue remodeling. Thus, it is very likely that phytochemicals, which are characterized by antioxidant and anti-inflammatory activity, will become useful in providing protective effects. Antioxidant and anti-inflammatory activity of substances found in *P. crassipes* points to the possibility of respiratory protection, however, there is a lack of studies in the area of more concrete evaluation of this kind of protection. This fact is of importance as respiratory toxicity is one of the main outcomes of pollution-related environmental problems. Given the molecular activities of its phytochemicals, *P. crassipes* seems to have a good potential for studies in the sphere of respiratory toxicity research in the future.

Detoxification and Environmental Health Applications

An unusual but important aspect of the therapeutic potential of *P. crassipes* is its capacity for environmental detoxification. While not a therapeutic effect in the conventional pharmacological sense, the ability of the plant to remove environmental pollutants has indirect implications for public health. Sierra-Carmona *et al.*, [29] highlighted the diverse applications of *P. crassipes* in sustainable environmental management. Building upon these observations, Fan *et al.* [19] demonstrated the remarkable ability of the plant to accumulate and remove heavy metals from contaminated aquatic systems. Such

properties reflect the existence of sophisticated endogenous defense mechanisms involving metal-binding compounds, antioxidants, and stress-response metabolites. The capacity to thrive under highly contaminated conditions further supports the notion that *P. crassipes* possesses biologically active metabolites capable of protecting cellular systems against environmental stressors [32, 33].

Nanobiotechnological and Biomedical Applications

The advancement of nanotechnology in recent years broadened the application of *P. crassipes* plants beyond traditional phytotherapy. The authors Shinde et al. [28] as well as Semu et al. [25] demonstrated the importance of utilizing plant extracts in the green synthesis of nanoparticles with useful antimicrobial action. Likewise, Harikrishnasagar et al. [34] focused on the importance of acquiring nanoparticles from the identified weed for the biological applications. These studies are of great importance since they demonstrate one of the possible uses of phytochemicals sourced from *P. crassipes* in various biomedical processes. Even though the field of applications related to the use of nanoparticles is very different from that of herbal medicine, it allows broadening the area of application for the species in question.

Potential Role in Circular Bioeconomy and Sustainable Health Products

The growing interest in sustainable utilization of invasive species has led to the exploration of *P. crassipes* as a source of high-value products. Muñoz et al. [35] reviewed scientific and technological innovations involving water hyacinth biomass and highlighted opportunities for generating bioactive products, nutraceuticals, biomaterials, and pharmaceutical ingredients. Similarly, Cherwoo et al. [13] emphasized the potential contribution of *P. crassipes* to circular bioeconomy models, whereby environmental management and resource recovery are integrated. These perspectives suggest that the medicinal exploitation of *P. crassipes* may simultaneously contribute to ecosystem management and healthcare innovation. The therapeutic potential of *Pontederia crassipes* extends beyond its traditional perception as an invasive aquatic weed. Current evidence consistently supports antioxidant and antimicrobial activities, while emerging data indicate promising anti-inflammatory, cytoprotective, hepatoprotective, respiratory protective, and nanobiotechnological applications. Across studies, phenolic compounds, flavonoids, triterpenoids, phytosterols, and quinone derivatives emerge as the principal bioactive constituents responsible for these effects [36].

Safety and Toxicity of *Pontederia crassipes*

The growing interest in the medicinal utilisation of *Pontederia crassipes* necessitates careful evaluation of its safety and toxicity profile. Although the plant contains numerous bioactive compounds with promising pharmacological properties, its ability to thrive in polluted aquatic environments raises concerns regarding the accumulation of heavy metals, pesticides, and other environmental contaminants. The extensive root system of *P. crassipes* efficiently absorbs and concentrates toxic

substances from water, making the safety of plant-derived preparations highly dependent on harvesting location and environmental quality [19, 29, 37]. Recent phytochemical investigations have further highlighted the medicinal potential of the species. Adeloye et al. [22] isolated two previously undescribed tetralin-linked pentacyclic triterpenoid conjugates from *P. crassipes* and demonstrated favourable in silico interactions with HIV-related molecular targets. The study also predicted acceptable drug-likeness characteristics and promising pharmacokinetic behaviour, suggesting potential therapeutic applicability. However, the authors emphasised that computational predictions alone cannot establish safety, and comprehensive toxicological studies are required to validate the biological effects and toxicity profiles of these newly identified compounds [38-40]. Ecological and environmental studies indicate that water hyacinth functions as an efficient phytoremediator, accumulating metals and organic pollutants that may subsequently pose risks if medicinal preparations are derived from contaminated biomass [41]. Moreover, variations in habitat conditions can significantly influence phytochemical composition and biological activity, potentially affecting both efficacy and safety [42, 43]. Despite increasing reports of antioxidant, antimicrobial, and therapeutic activities, systematic acute, sub-chronic, chronic, genotoxicity, and reproductive toxicity studies remain scarce. Therefore, rigorous toxicological evaluation, contaminant screening, and phytochemical standardization are essential prerequisites for the safe medicinal development of *P. crassipes*.

Sustainable Applications and Future Perspectives

Pontederia crassipes to be recognized more and more, the focus is changing from dealing with its invasion problem to the efficient use of the plant. Previously, water hyacinth was seen as a harmful being for all freshwater bodies, but now its applications are being studied in depth and suggest tackling important environmental issues while bringing economic gains [44, 38]. Some of the results of a review by Sierra-Carmona, Hernández-Orduña and Murrieta-Galindo [45] show that numerous functions of *P. crassipes* have been discovered, such as treatment of wastewater, compost production, animal feed, biofertilizers, bioenergy generation, and production of advanced biomaterials. After this review, Cherwoo et al. [13] provided a circular bioeconomy concept in which the harvested mass of water hyacinth being turned into marketable products is turning ecological problem into economic gain. It is also worth noting that it has great phytoremediation capacity as it helps the extraction of heavy metals from water [46].

Recently conducted phytochemical studies have unveiled its potential uses in biomedicine, which include the discovery of active compounds with antioxidant, antimicrobial, anti-inflammatory, and cytoprotective action [47, 48]. However, before its mass use in medicine, we need to standardize the growing process, monitor the possible contamination, check phytochemical compounds, and test for safety. The vision of how investigations will be performed in the future has to incorporate ecological

management and pharmaceutical and biotechnology innovations in order to assure the sustainable use of *P. crassipes* and eliminate its invasiveness [49, 50].

CONCLUSION

Water hyacinth (*Pontederia crassipes*) has been considered one of the world's invasive aquatic plants, causing ecological problems because of its fast growth and broad distribution. However, the research shows that the species could be useful scientifically and medicinally as well. According to the latest results of research, the plant is rich in bioactive agents, such as phenolic compounds, flavonoids, triterpenoids, phytosterols, and quinone derivatives, which are responsible for the antioxidant, anti-inflammatory, antimicrobial, and cytoprotective properties of the plant. Some of the promising applications of the species include its use in phytoremediation, nanotechnology, and bioenergy production. Nevertheless, current studies on the plant's properties are mainly conducted through phytochemical and in vitro experiments. Future research should aim to ensure the standardization of its technology and carry out toxicological and mechanistic studies.

Conflicts of interest

The authors declare no conflict of interest.

Source of funding

Self-funding

Acknowledgement

The authors express their sincere gratitude to the taxonomist for the accurate identification and classification of *Pontederia crassipes*, which greatly contributed to the scientific integrity of this study. We also extend our heartfelt thanks to the departmental staff for their invaluable assistance in preparing this study with precision and dedication.

REFERENCES

1. Latif R, Nawaz T. Medicinal plants and human health: a comprehensive review of bioactive compounds, therapeutic effects, and applications. *Phytochemistry Reviews*. 2026 Mar;25(3):2299-342.
2. El-Saadony MT, Saad AM, Mohammed DM, Korma SA, Alshahrani MY, Ahmed AE, Ibrahim EH, Salem HM, Alkafaas SS, Saif AM, Elkafas SS. Medicinal plants: bioactive compounds, biological activities, combating multidrug-resistant microorganisms, and human health benefits-a comprehensive review. *Frontiers in immunology*. 2025 Apr 28;16:1491777.
3. Xu Z, Chang L. Pontederiaceae. In *Identification and Control of Common Weeds: Volume 3* 2017 Nov 11 (pp. 807-819). Singapore: Springer Singapore.
4. Omondi EA, Ndiba PK, Njuru PG. Characterization of water hyacinth (*E. crassipes*) from Lake Victoria and ruminal slaughterhouse waste as co-substrates in biogas production. *SN Applied Sciences*. 2019 Aug;1(8):848.
5. Datta A, Maharaj S, Prabhu GN, Bhowmik D, Marino A, Akbari V, Rupavatharam S, Sujeetha JA, Anantrao GG, Poduvattil VK, Kumar S. Monitoring the spread of water hyacinth (*Pontederia crassipes*): challenges and future developments. *Frontiers in Ecology and Evolution*. 2021 Jan 28;9:631338.
6. Ielmini MR, Sankaran KV. Invasive alien species: A prodigious global threat in the anthropocene. *Invasive alien species: observations and issues from around the world*. 2021 Apr 23;1:1-79.
7. Sierra-Carmona CG, Hernández-Orduña MG, Murrieta-Galindo R. Alternative uses of water hyacinth (*Pontederia crassipes*) from a sustainable perspective: a systematic literature review. *Sustainability*. 2022 Mar 26;14(7):3931.
8. Brito LD, Lillebø AI, Teixeira H. Global distribution of *Pontederia crassipes*: a systematic and bibliometric review of biomass variations and environmental correlations. *Frontiers in Environmental Science*. 2026 Mar 25;14:1703625.
9. Thinh PN. Management Strategies for *Pontederia Crassipes*. *Reviews in Agricultural Science*. 2025;13(4):49-60.
10. Kato M, Kato-Noguchi H. The Impact of Water Hyacinth (*Pontederia crassipes*) on Freshwater Ecosystems: Ecological and Socioecological Significance. *Sustainability*. 2026 May 27;18(11):5390.
11. Omondi EA, Ndiba PK, Njuru PG. Characterization of water hyacinth (*E. crassipes*) from Lake Victoria and ruminal slaughterhouse waste as co-substrates in biogas production. *SN Applied Sciences*. 2019 Aug;1(8):848.
12. Sierra-Carmona CG, Hernández-Orduña MG, Murrieta-Galindo R. Alternative uses of water hyacinth (*Pontederia crassipes*) from a sustainable perspective: a systematic literature review. *Sustainability*. 2022 Mar 26;14(7):3931.
13. Cherwoo L, Kumar S, Das S, Datta A, Verma S, Prabhu NG, Oo HN, Sharma A, Bhondekar AP. Transforming aquatic weeds into resources: *Pontederia crassipes*, water hyacinth mining for circular bioeconomy. *Environmental Management*. 2025 Sep;75(9):2458-78.
14. Costa MF, Luiz MM, de Souza LC, Tempone AG, Lago JH, Nascimento IR. Phenylanthracene anhydrides from water hyacinth (*Pontederia crassipes* Mart.). *Phytochemistry Letters*. 2021 Dec 1; 46:1-5.
15. Gettys LA. Inheritance of morphological characters of pickerelweed (*Pontederia cordata* L.). University of Florida; 2005.
16. Jangpangi D, Patni B, Chandola V, Chandra S. Medicinal plants in a changing climate: understanding

- the links between environmental stress and secondary metabolite synthesis. *Frontiers in Plant Science*. 2025 Jun 13; 16:1587337.
17. Fathima Hanna K, Thasni M, Krishna P, Renjitha K, Thomas B. Invasive Aquatic plants and their distribution: A Case Study. *Aquatic*. 2024 Oct 5.
 18. Roberts J, Zulkeflee Z, Nikkel E, Clements DR, Florentine S. The Biology, Ecology, Distribution and Future Management Challenges of the Invasive Species *Pontederia crassipes* (Water Hyacinth): A Global Review. *Weed Research*. 2026 Jan;66(1):e70058.
 19. Fan Y, Zhang S, Wang X, Yang L, Li H, Gao K. The potential of *Pontederia crassipes* to remediate heavy metals in water. *Plants*. 2025 Nov 26;14(23):3604.
 20. Misra D, Dutta W, Prieto JG, Ray P. Impact of Biocontrol Agents on Biochemical Changes of Aquatic Weed Water Hyacinth, *Pontederia crassipes* (Mart.) Solms-Laubach.
 21. Bakrim WB, Ezzariai A, Karouach F, Merghoub N, Drissi B, Kibret M, Hafidi M, Kouisni L. Phytochemical profiling, biological activities, and in silico molecular docking studies of water hyacinth (*Pontederia crassipes* Mart.) aerial part extracts. *Biocatalysis and Agricultural Biotechnology*. 2025 Aug 20:103733.
 22. Adeloye AO, Manesa KC, Idowu TO, Babatunde DD, Magwa NP. Two Novel Tetralin-Linked Pentacyclic Triterpenoid Conjugates from Water Hyacinth (*Pontederia Crassipes*) (Mart.) Solms: Isolation, Structure Elucidation and In-Silico Anti-Hiv Computational Studies. *Structure Elucidation and In-Silico Anti-Hiv Computational Studies*. 2025.
 23. Kandulo MJ. *In Vitro and in Silico Antimicrobial Activity of Pontederia crassipes (Namasipuni) Isolates (Hydroquinone) Against Selected Veterinary Bacteria* (Master's thesis, Malawi University of Science and Technology).
 24. Ben Bakrim W, Ezzariai A, Mahdi I, Karouach F, Merghoub N, Kibret M, Hafidi M, Kouisni L. GC-MS profiling, biological activities and molecular docking of total sterol extracts from *Pontederia crassipes* (Lake Tana, Ethiopia). *Scientific Reports*. 2026 Mar 22;16(1):14516.
 25. Semu TC, Williams J, Cheng J, Mutingwende I, Chifamba J. *Pontederia crassipes* Biosynthesised Silver Nanoparticles (AgNPs), Characterisation and Activity against Multidrug-Resistant Microbes. *J. Adv. Med. Pharm. Sci*. 2024 Apr 26;26(6):90-103.
 26. Rabbani G, Wagay JA, Ali MS, Al-Lohedan HA, Gill HS, Bhati KK, Kant R, Umar K, Mandal S. Unlocking the nematocidal potential of *Pontederia crassipes* leaf extract against *Meloidogyne javanica*: In vitro, greenhouse, phytochemical, and in silico analyses. *Physiological and Molecular Plant Pathology*. 2026 Jun 12:103281.
 27. de Lima DV, Lima Filho CM, Pacheco AB. Seasonal variation in the phytoremediation by *Pontederia crassipes* (Mart) Solms (water hyacinth) and its associated microbiota. *Ecological Engineering*. 2022 Oct 1; 183:106744.
 28. Shinde RA, Adole VA, Jagdale BS, Pawar TB. Experimental and Theoretical Studies on the Molecular Structure, FT-IR, NMR, HOMO, LUMO, MESP, and Reactivity Descriptors of (E)-1-(2, 3-Dihydrobenzo [b] [1, 4] dioxin-6-yl)-3-(3, 4, 5-trimethoxyphenyl) prop-2-en-1-one. *Material Science Research India*. 2020; 17:54-72.
 29. Ratnani RD, Arianti FD, Sasongko NA. Exploring the potential of water hyacinth weed (*Pontederia crassipes*) as an environmentally friendly antifungal to realize sustainable development in lakes: A review. *Case Studies in Chemical and Environmental Engineering*. 2024 Jun 1; 9:100702.
 30. Karunaratne DR, Ranasinghe SM, Ranasinghe NS, Thilakarathne AS, Jayakody A. Evaluating the antibacterial activity of *Pontederia crassipes*, an invasive alien plant, against multidrug resistant bacteria using In-vitro and In-silico techniques: a comprehensive review. *Transformative applied research*.:315-23.
 31. Jagessar R, Samaroo A. Antimicrobial Properties of *Pontederia cordata* Extract. *Chem Pharm Res*. 2025; 7 (3): 1-6. Correspondence: Jagessar R, Lecturer and Professor in Chemistry, Department of Chemistry, Faculty of Natural Sciences, University of Guyana. Received. 2025 Aug;14.
 32. Julien M. *Eichhornia crassipes* (Martius) Solms-Laubach–Water Hyacinth.
 33. Adelodun AA, Hassan UO, Nwachukwu VO. Environmental, mechanical, and biochemical benefits of water hyacinth (*Eichhornia crassipes*). *Environmental Science and Pollution Research*. 2020 Aug;27(24):30210-21.
 34. Harikrishnasagar V, Susha VS, Ameena M, Pillai PS, Manju RV, Anith KN, Ghosh S, Swathika N. Use of silver nanoparticles biosynthesized from leaf extracts of three allelopathic weeds for the management of water hyacinth (*Pontederia crassipes* Mart.). *Indian Journal of Weed Science*. 2025;57(3):334-42.
 35. Muñoz AL, Perez BK, Calderon AV, Morales MA. Scientific and technological perspectives of the water lily (*Pontederia crassipes*): Innovative applications of its biomass. *Hidrobiológica*. 2025 Dec 18;35(3).
 36. Fletcher J, Willby N, Oliver DM, Quilliam RS. Phytoremediation using aquatic plants. *InPhytoremediation: in-situ applications* 2020 Mar 20

- (pp. 205-260). Cham: Springer International Publishing.
37. Téllez TR, López EM, Granado GL, Pérez EA, López RM, Guzmán JM. The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions*. 2008 Mar;3(1):42-53.
 38. Lalitha P, Sripathi SK, Jayanthi P. Secondary metabolites of *Eichhornia crassipes* (Water hyacinth): a review (1949 to 2011). *Nat Prod Commun*. 2012;7(9):1249-1256.
 39. Aboul-Enein AM, Al-Abd AM, Shalaby E, et al. *Eichhornia crassipes* (Mart) solms: from water parasite to potential medicinal remedy. *Plant Signal Behav*. 2011;6(6):834-836. doi:10.4161/psb.6.6.15166
 40. Ben Bakrim W, Ezzariai A, Karouach F, et al. *Eichhornia crassipes* (Mart.) Solms: A Comprehensive Review of Its Chemical Composition, Traditional Use, and Value-Added Products. *Front Pharmacol*. 2022; 13:842511. Published 2022 Mar 18. doi:10.3389/fphar.2022.842511
 41. Madikizela LM. Removal of organic pollutants in water using water hyacinth (*Eichhornia crassipes*). *J Environ Manage*. 2021; 295:113153. doi:10.1016/j.jenvman.2021.113153
 42. Rezaia S, Ponraj M, Talaiekhazani A, et al. Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. *J Environ Manage*. 2015; 163:125-133. doi:10.1016/j.jenvman.2015.08.018
 43. Victor KK, Séka Y, Norbert KK, Sanogo TA, Celestin AB. Phytoremediation of wastewater toxicity using water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*). *Int J Phytoremediation*. 2016;18(10):949-955. doi:10.1080/15226514.2016.1183567
 44. Saha P, Shinde O, Sarkar S. Phytoremediation of industrial mines wastewater using water hyacinth. *Int J Phytoremediation*. 2017;19(1):87-96. doi:10.1080/15226514.2016.1216078
 45. Jones JL, Jenkins RO, Haris PI. Extending the geographic reach of the water hyacinth plant in removal of heavy metals from a temperate Northern Hemisphere River. *Sci Rep*. 2018;8(1):11071. Published 2018 Jul 23. doi:10.1038/s41598-018-29387-6
 46. Peng H, Wang Y, Tan TL, Chen Z. Exploring the phytoremediation potential of water hyacinth by FTIR Spectroscopy and ICP-OES for treatment of heavy metal contaminated water. *Int J Phytoremediation*. 2020;22(9):939-951. doi:10.1080/15226514.2020.1774499.
 47. Qin H, Diao M, Zhang Z, et al. Responses of phytoremediation in urban wastewater with water hyacinths to extreme precipitation. *J Environ Manage*. 2020; 271:110948. doi:10.1016/j.jenvman.2020.110948
 48. Abbas Z, Arooj F, Ali S, Zaheer IE, Rizwan M, Riaz MA. Phytoremediation of landfill leachate waste contaminants through floating bed technique using water hyacinth and water lettuce. *Int J Phytoremediation*. 2019;21(13):1356-1367. doi:10.1080/15226514.2019.1633259
 49. Newete SW, Byrne MJ. The capacity of aquatic macrophytes for phytoremediation and their disposal with specific reference to water hyacinth. *Environ Sci Pollut Res Int*. 2016;23(11):10630-10643. doi:10.1007/s11356-016-6329-6
 50. Hasnat H, Riti SJ, Shompa SA, et al. Unveiling the Therapeutic Potentials of Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms) Flower against Oxidative Stress, Inflammation and Depressive Disorders: GC-MS/MS, in Vitro, In Vivo and in Silico Approaches. *Chem Biodivers*. 2024;21(12):e202401268. doi:10.1002/cbdv.202401268