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Eichhornia crassipes (Water Hyacinth) Multifaceted Potential due to Many Therapeutic and Value-added Aspects

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Abstract

Background: *Eichhornia crassipes*, more often known as the water hyacinth, a member of the Pontederiaceae family, is a notoriously invasive macrophyte that inhabits watery habitats. Areas in the tropics and subtropics are its native habitats. Despite its pejorative reputation, water hyacinth causes major ecological issues, such as the depletion of water supplies. It serves a variety of purposes. Animal feed, bioenergy, biofertilizer, and industrial wastewater treatment are only a few of its numerous societal and economic applications. **Aim:** To identify research gaps and highlight the need for more extensive pharmacological investigations on this medicinal plant. **Methods:** We performed a literature search on ScienceDirect and PubMed databases using various keywords, including "water hyacinth". The search was refined by applying relevant filters to obtain the most pertinent articles for this review article's objective. **Results:** Alkaloids, sterols, tannins, saponins, flavonoids, phenols, and water hyacinth are just a few of the many bioactive plant components found in abundance in this plant. Many different medicinal effects have been associated with these secondary metabolites. Among its many pharmacological effects are those of an antioxidant, anti-inflammatory, antibacterial, neuroprotective, and hepatoprotective nature, among many others. **Conclusion:** The *E. crassipes* (Mart.) plant's pharmacologically active components have been the subject of much study. It still needs to carry out an extensive investigation of the pharmacological properties of this medicinal plant. This review provides a thorough synopsis of the literature on *E. crassipes*, including its traditional usage, pharmacological and biological properties, and chemical composition.

Major Findings: *Eichhornia crassipes* contains a rich spectrum of secondary metabolites, including alkaloids, sterols, tannins, saponins, flavonoids, and phenolic compounds. These phytochemicals demonstrate diverse pharmacological effects, such as antioxidant, anti-inflammatory, antibacterial, neuroprotective, and hepatoprotective activities.

Keywords: Economic Application, *Eichhornia crassipes* Solms, Pharmacology, Phytoconstituents

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1. Introduction

The big floating aquatic weed known as one member of the *Pontederiaceae* family is the water hyacinth, scientifically known as *Eichhornia crassipes*. This plant is native to a wide range of tropical and subtropical regions, such as the Amazon, Africa, Egypt, Sudan, Brazil, Kenya, Ethiopia, Nigeria, Zimbabwe, Zambia, and South Africa, in addition to its native countries of origin in those areas. The key characteristics of this plant include its rapid and extensive growth, as well as its high tolerance to variations in pH, nutrient availability, and temperature. *E. crassipes* can survive across a wide range of environmental conditions, contributing to

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its aggressive spread[1]. The International Union for Conservation of Nature (IUCN) classifies it among the 100 most invasive species worldwide and one of the top 10 most problematic weeds. Despite its invasive nature, the plant also possesses several beneficial applications[2-4]. Its ability to thrive in polluted water while absorbing heavy metals has made it a popular phytoremediation agent for use in wastewater treatment[5,6]. It could also be used as a biofertilizer and a bioenergy source[7,8]. Traditional uses of the herb include curing gastrointestinal issues such as intestinal parasites, indigestion, diarrhoea, and gas. The plant's many bioactive components exhibit a vast array of biological and pharmacological effects. All botanical descriptions were represented in Table 1. A few examples are compounds that have antioxidant, antibacterial, antitumor, anticancer, anti-inflammatory, hepatoprotective, larvicidal, and wound-healing properties[9-11]. There have been a lot of patents filed thus far; most of them concern plant-based medicines and their preparations. This review study examines the phytochemical composition, medicinal uses, and pharmaceutically relevant characteristics of water hyacinth, as well as any patents that have been registered on the plant[12-19].

1.1 Botanical Description

Table 1. Plant profile of *Eichhornia crassipes*[19-25]

Botanical Name	*Eichhornia crassipes (Pistia stratiotes)*
Synonyms	*Eichhornia cordifolia* Gand., nom. illeg., *Piaropus meromelia's* Raf. *Pontederia crassicaulis* Schltdl., *orth. var.*
Kingdom	*Plantae*
Division	*Magnoliophyta*
Class	*Monocots*
Order	*Commelinales*
Family	*Pontederiaceae*
Genus	*Eichhornia*
Species	water hyacinth, *Eichhornia diversifolia* – variable leaf water hyacinth, *Eichhornia natans*
Ayurvedic name	*Jalkumbhi, Variparni, Kumbhik*
Hindi name	*Jalkumbhi*
Bengali Name	*Tokapana*
Origin	India, during the British colonial rule, as an ornamental aquatic plant from South America

1.2 Origin (History)

The global spread of *Eichhornia crassipes* has resulted in its invasion of several continents, including North America, Europe, Africa, and Australia. In South America, reports of its occurrence began in 1902 in Brazil, 1942 in Argentina, 1959 in Paraguay, Uruguay, Bolivia, Ecuador, and Colombia, 1976 in Venezuela, and 1979 in Chile. The plant originally came to India in 1896 from Brazil as a decorative plant[26].

1.3 Common Names in the Various Regions of the World

Aguapé, baronesa (Brazil), *zanim, jacinto-aquatico* (Portugal), *bisnidh*, and *zoqqueym*, *ettani*, these names come from several countries: Egypt (*baqaqa, habba, halassandi/halassant*), Colombia (*buchón*), Venezuela (*bora*), France (*jacinthe d'eau*), Pakistan (*gulbakauli*), *jacinto de agua, camalote, lechuguilla, lirioacuatico* (Spain*), lila de agua* (Dominican Republic), *tokozelka* (former Zechoslovakia), *top-chawa* (Thailand), *violeta de agua* (Chile), *wampee* (former USSR), *wasserhyazinthe* (Germany), *susümbülü* (Turkey), *tarulla* (Colombia), *vanhyacint* (Denmark), water hyacinth (United Kingdom and India), *yakintonhamaim* (Israel)[27-30]. All Vernacular names and taxonomical descriptions were represented in Tables 2, 3 and 4.

1.4 Cultivation

Water hyacinth, or *Eichhornia crassipes*, is an aquatic plant native to the Amazon basin that grows rapidly and floats freely. Ponds, lakes, rivers, and wetlands are ideal habitats for this plant since they are warm and contain nutrients. The plant spreads quickly through the soil via vegetative means (stolons), making cultivation a breeze. Water that is neither too fast nor too sluggish, with a temperature range of 25 to 30 °C and a pH of 6.5–8.5, is good for growth. It requires a lot of sunshine and water that is rich in nitrogen and phosphorus. The ability to multiply by a factor of two makes it one of the most rapidly expanding aquatic plants in the world, with its biomass in as little as 5–15 days under optimum circumstances. Mature plants are placed in shallow pools of fresh water or tanks for cultivation. Because excessive growth can suffocate aquatic habitats and reduce oxygen levels, water quality monitoring is crucial. For this reason, research on biomass utilisation necessitates controlled cultivation, preferably in man-made ponds

Table 2. Vernacular names of *Eichhornia crassipes* in India

Hindi:	*Jal kumbha*
English:	Water hyacinth
Kannada:	*Antarataavare, Antarangange Manipuri: Kabokkang*
Mizo:	*Dum-awr-puar*
Sanskrit:	*Jalakumbhi, Variparni*
Telugu:	*Budaga Tamara, Gurrapu dekka moka*
Tamil:	*Vengaya thamarai*

Table 3. Taxonomy of *Eichhornia crassipes*[31-40]

Domain:	*Ukaryota*
Kingdom:	*Lantae*
Phylum:	*Spermatophyta*
Subphylum:	*Angiospermae*
Class:	*Monocotyledonae*
Order:	*Pontederiales*
Family:	*Pontederiaceae* Genus: *Eichhornia*
Species:	*Eichhornia crassipes*
Geographical Distribution:	Globally dispersed, *E. crassipes* is at its most abundant in the tropics and subtropics. Spain, Portugal, Jordan, Italy, and Israel make up the EPPO area. Here are several Asian countries: Cambodia, China, Brunei Darussalam, India, Indonesia, Lebanon, Japan, Laos, Malaysia, Singapore, Sri Lanka, Syria, Taiwan, Thailand, and Vietnam. The United States of America (USA) and Mexico (specifically the states of Alabama, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, and Texas).
Phenology:	Flowering: May to December. Fruiting: July to December.
Habitat:	Water hyacinth is a floating plant, found in rivers and lakes with a tropical or subtropical climate, particularly in areas where plant nutrients are abundant.

or lined tanks. Even though *E. crassipes* is considered an invasive species in many parts of the world because of how quickly it spreads. It is actually grown for purposes such as bioremediation, bioenergy, crafts, and medical research. Preventing ecological imbalance while making use of its economic and medical potential requires sustainable management strategies[42-55]. All parts of plants were represented in Figure 1, and the morphological characteristics are in Table 4**.**

1.5 Phytochemical Constituents

The therapeutic and antioxidant qualities of *Eichhornia crassipes* are due in large part to the large variety of bioactive compounds it contains. Some of the important components include phenolic chemicals, alkaloids, tannins, saponins, terpenoids, glycosides, and flavonoids like quercetin and luteolin. Its blossoms, roots, and leaves are the main sources of these chemicals. In addition to vitamins A, C, and E, the plant includes sterols, fatty acids, and amino acids. The antioxidant and neuroprotective effects of flavonoids and phenolics are of paramount importance, while the anti-inflammatory and antibacterial capabilities of alkaloids are also noteworthy. One advantage of this plant for phytoremediation is that its roots can absorb harmful substances like heavy metals. Many studies have looked at *E. crassipes* as a potential treatment for oxidative stress, central nervous system diseases, and microbial infections because of its extensive phytochemical profile[56-58]. The percentage of chemical constituents is represented in Figure 2, and the types of chemical constituents are shown in Figures 3 and 4.

1.6 Bioactive and Pharmacological Action

Medicinal plants can serve as both medicinal agents and raw materials for the creation of successful

Table 4. Morphological characteristics

Leaves	Round, wide, thick, glossy, green, and measuring 10–20 cm (4–8 in) in diameter; broad, thick, and waxy.
Stems	Having air bladders at the base, these upright, spongy stems can reach a length of 50 cm (20 in)
Flowers	Display, lavender-blue, six-petaled flowers with a centre yellow splotch, eight to fifteen blooms per 30-centimetre-long spike, and they open in the middle of summer.
Fruit and seeds	Seed pod, 3-celled, many tiny seeds.
Roots	Feathery, freely hanging, purple black
Reproduction	By fragmentation of stolons, adventitious root system, and to a lesser extent, by seed.
Useful Part	Whole plant

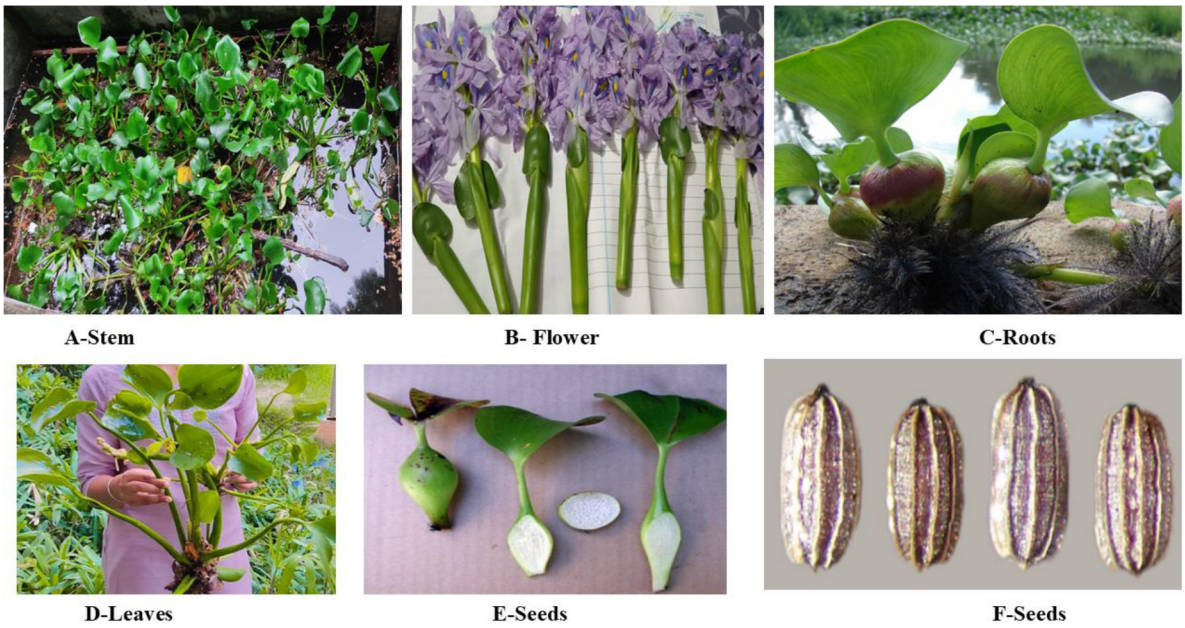


Figure 1. Different parts of *Eichhornia crassipes*[41].

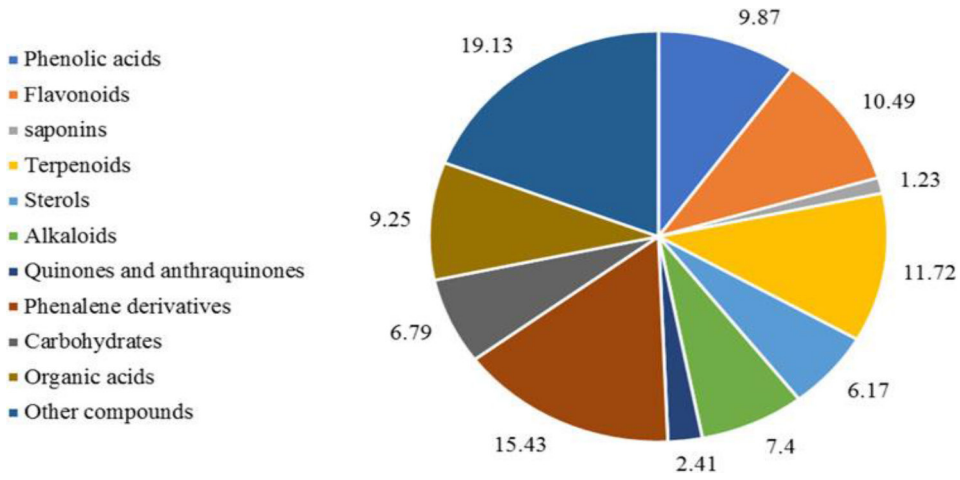


Figure 2. The main groups of compounds found in *E. crassipes*, broken down by the total amount of phytochemicals. The most abundant phytochemical classes and subclasses of substances extracted from *E. crassipes*.

pharmaceuticals; they play an essential role in the modern pharmaceutical industry. Plants contain a large number of secondary metabolites, such as alkaloids, glycosides, tannins, volatile oils, and many more, which have been well-documented and bode well for the future of pharmacological activity and the development of new drugs. Some *Eichhornia crassipes*'s pharmacological actions is given below.

1.6.1 Analgesic and Relaxant Characteristics

A promising analgesic capacity to inhibit acetic acid-induced writhing in experimental mice was used to illustrate the characteristic of the ethanol extract of *E. crassipes* leaves. This finding raises the possibility that the extract contains potential analgesic properties. In addition to relieving pain, the extract also has a calming effect. Experimental models with mice showed an increase in sleep duration and latency after administration of the extract. In addition, the mice's upright posture was maintained by the extract throughout the sedation period, which indicates that the sedative effect was continuous and long-lasting. The extract demonstrated a dose-dependent sedative effect by prolonging the latency durations associated with sleep induction. These

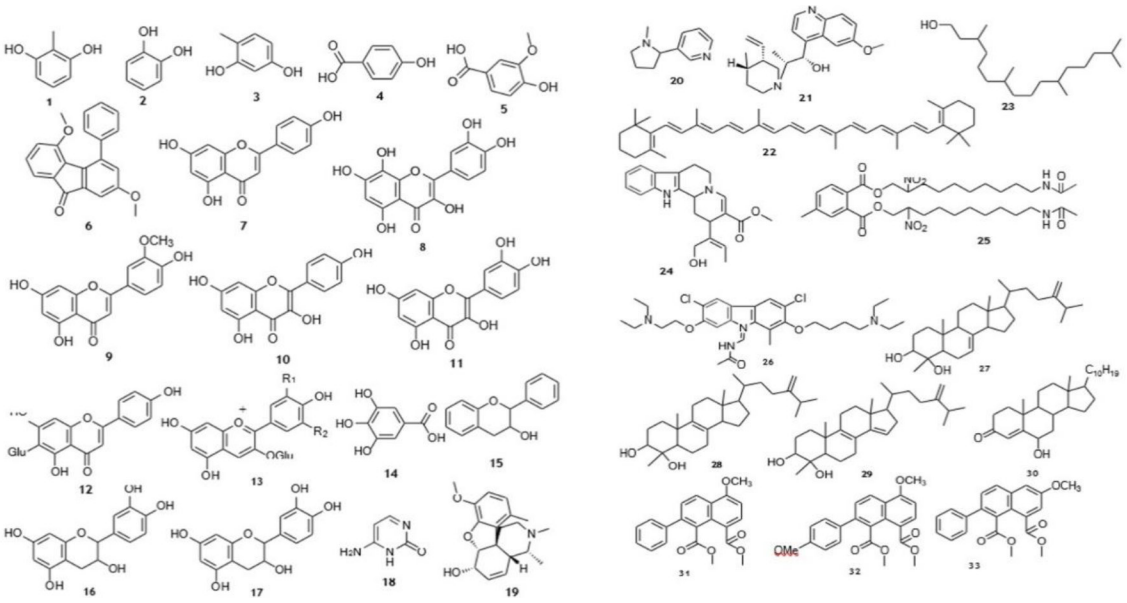


Figure 3. Suggested structures of natural products reported from *E. crassipes*[59,60].

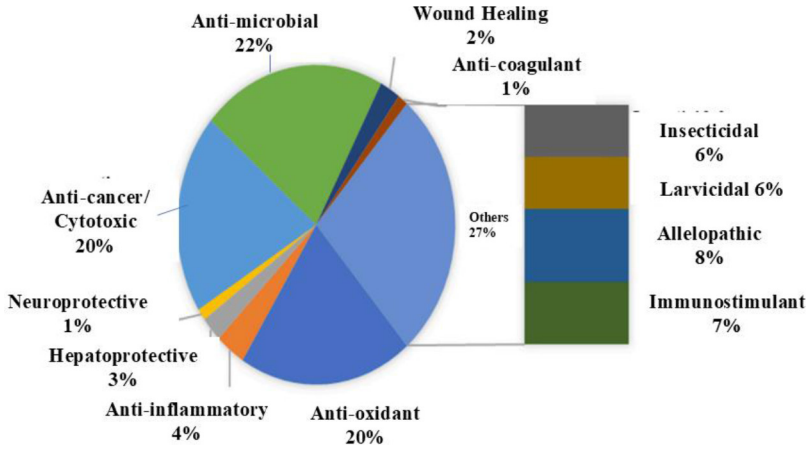


Figure 4. Proportion of the examined biological and pharmacological activity of *E. crassipes* as reported in the literature.

findings highlight the intricate pharmacological profile of the ethanol extract of *E. crassipes* leaves. Its analgesic and sedative properties make it a promising candidate for the treatment of pain- and sleep-disrupting diseases. The observed analgesic activity highlights the extract's capacity to change pain perception, as shown by the inhibition of the writhing response caused by acetic acid. Potentially responsible for this effect is its interaction with systems of neurotransmitters involved in nociceptive transmission or pain pathways. Similarly, the extract may have depressive effects on the central nervous system due to its sedative properties. The extract's calming effects might be due to its ability to modulate neurotransmitter systems that play a role in sleep regulation, like GABAergic or serotonergic pathways. This scenario would explain why it lengthens the duration and latency phases of sleep. This study adds to our understanding of the sedative and analgesic effects of *E. crassipes* ethanol extract, which is an important component of its pharmacological profile. Additional study is necessary to fully comprehend its therapeutic potential in clinical settings, including its profile of safety and its action mechanisms[60-65].

1.6.2 CNS Depressant and Anti-anxiety Effects

Due to its ability to decrease exploratory behaviour patterns, the ethanol extract of *Eichhornia crassipes*

leaves exerts strong central nervous system depressive effects in evasion tests. These findings suggest that the extract might change neurotransmitter systems or neuronal pathways associated with motor control and exploratory behaviour, thereby inhibiting central nervous system activity. The inhibitory effects on motor activity provide more evidence of the extract's CNS-depressing properties and suggest that it could be used as a pharmaceutical treatment for disorders associated with hyperactivity or motor agitation. In addition to its potential effects on the central nervous system, the ethanol extract of *E. crassipes* shows outstanding potential in reducing anxiety. Experiments have shown that giving the extract makes people act differently when they're anxious, such as spending less time moving around in new places or more time doing things that make them feel better. One possible explanation for the extract's calming effects is its ability to modify neurotransmitter systems that play a role in anxiety regulation, such as the GABAergic or serotonergic pathways[63,66]. Possible therapeutic benefits for anxiety-related disorders may be derived from the extract's anxiolytic properties, which it may achieve by reducing stress response pathways or increasing inhibitory neurotransmission. Anxiolytic and central nervous system depressant effects are displayed by the ethanol extract derived from the leaves of *E. crassipes* displays a diverse range of pharmacological properties. These findings highlight its promise as a therapeutic modality for a variety of conditions, including motor hyperactivity disorder and anxiety disorder. Additional research is required to determine its therapeutic utility in treating disorders associated with the central nervous system and to elucidate the underlying mechanisms of action. Histopathological evidence demonstrates that the extract can protect brain tissue from degenerative alterations and reduce neuronal damage. Such neuroprotective benefits are crucial in the context of mental illnesses, as symptoms are often caused by structural abnormalities and neuronal malfunction. In addition, alterations in astrocyte and microglial activity, among other glial responses, suggest that the extract exerts complex control over neuroinflammatory processes. This modulation likely alleviates neuroinflammation and restores brain homeostasis, which could explain its potential antipsychotic effects. In addition, glial responses observed in brain regions associated with mood provide histological evidence that the extract may possess antidepressant properties. One possible mechanism by which the extract exerts its antidepressant effects is by influencing neuroplasticity and neurotransmitter function via modulating glial activity. Despite the interest in *E. crassipes* due to its neuroprotective and psychiatric effects, further research is needed to understand the exact mechanisms by which it exerts these effects. To sum up, the histopathological data provide credence to the hypothesis that *E. crassipes* extract could be a promising treatment for mental health concerns. Its potential antidepressant effects, neuroprotective qualities, and antipsychotic benefits make it an important player in psychiatric pharmacology. But, to fully understand and make use of its medicinal potential, additional research is necessary. Further studies comparing its safety and effectiveness with other psychiatric medications on the market and in clinical settings are required to establish its therapeutic value[67].

1.6.3 Anti-depressant Benefits

Eichhornia crassipes, often known as water hyacinth, has been identified by histopathological investigations as may help treat mental diseases and have neuroprotective properties. Mice administered *E. crassipes* extracts showed glial responses in their brains, suggesting the plant might be useful in treating mental diseases. The modulation of glial processes by the extract, which indicates neuroinflammation and neuronal injury, implies a neuroprotective action. By lowering neuroinflammatory processes and protecting neurons from damage, the extract may be useful in treating neurodegenerative or mental diseases. Also, the extract might have antidepressant qualities based on what glial reactions were observed. Changes in glial activity and neuroinflammation have been associated with the pathophysiology of depression; the extract's ability to modulate these processes could contribute to its antidepressant effects. Evidence from histopathology suggests that *E. crassipes* extract has great therapeutic potential. Its neuroprotective properties and possible antidepressant effects emphasise its significance in the treatment of mental diseases. The safety and efficacy in clinical settings, as well as the underlying mechanisms of action, need more investigation[68].

1.6.4 Memory Enhancement

The ethanol extract from *Eichhornia crassipes* shows promise for memory-related behaviours since it improves latency times and patterns of exploratory behaviour. This suggests that *E. crassipes* may help with neurocognitive diseases by enhancing cognitive function and memory. Improving latency times suggests better processing and retrieval of memories, whereas shifts in patterns of exploratory behaviour indicate changes to learning and memory consolidation processes. Given that memory loss and cognitive impairment characterise neurocognitive diseases, these findings are particularly intriguing. By enhancing memory-related activities, *E. crassipes* extract may offer therapeutic advantages in cases such as dementia and Alzheimer's disease. Because of its potential to modify neurotransmitter systems or neuronal pathways associated with memory creation and retention, the extract may enhance cognition. Additionally, the observed enhancements in memory-related behaviours support the notion that Neuroprotective effects are exhibited by *E. crassipes*. Overall cognitive performance and neurocognitive illness progression can be slowed by the extract's ability to preserve neuronal integrity and function. Taken together, the findings suggest that *E. crassipes* extract may have therapeutic potential in enhancing cognitive function and memory. More study is needed to determine its safety and effectiveness in clinical settings and to understand its underlying mechanisms of action. But these results do shed light on the potential applications of *E. crassipes* for neurocognitive disease treatment and cognitive enhancement[69-75].

1.6.5 Antimicrobial Activity

We tested some bacterial and fungal strains, including *Escherichia coli, Bacillus subtilis, Bacillus cereus, Lactobacillus casei, Aspergillus flavus, Aspergillus niger, Alternaria alternata, Colletotrichum gloeosporioides, Candida albicans*, and *Fusarium solani*, were tested using ethanol, acetone, methanol, n-butyl alcohol, and distilled water as extracts from *Eichhornia crassipes* to evaluate their antibacterial and antifungal properties. Minimal concentration required to prevent (MIC) test indicated that extracts from *E. crassipes* were effective against all of the bacteria and fungi that were tested, even at lower concentrations. For the treatment of *B. subtilis, F. solani*, and *C. gloeosporioides*, the antibacterial and antifungal effects are best achieved by methanol and butanol, respectively. The methanol extract of *E. crassipes* was examined for its antibacterial activity using the disc diffusion assay and Minimum Inhibitory Concentration (MIC) against *Vibrio cholerae* MTCC 1957 and *Staphylococcus aureus* MTCC 23313, two strains of Gram-negative bacteria. The disc diffusion experiment and minimum inhibitory concentration (MIC) of methanol extract demonstrated a concentration-dependent gradient value for bacterial inhibition. In addition, compared to Gram-negative bacteria, Gram-positive bacteria were discovered to be more susceptible[76-80].

1.6.6 Antioxidant Activity

To evaluate the antioxidant properties of *Eichhornia crassipes*, both the crude extract and the separated fractions were subjected to a DPPH scavenging activity test. The antioxidant activity of the compounds examined was highest for the crude extract, with the others displaying lower or comparable values. The antioxidant effects of several fractions were highly similar, with IC_{50} values ranging from 97.0 ± 5.4 to 97.4 ± 2.7 µg/ml[9]. The antioxidant activity of the methanolic extract of *E. crassipes* was investigated using two separate methods: the DPPH radical scavenging method and the hydrogen peroxide scavenging method. We measured the ability of methanol extract and ascorbic acid at different dosages to scavenge free radicals using the DPPH test. These results demonstrated that the extract was a potent free radical scavenger. A measurement of absorbance was taken at 517 nm after solutions with different concentrations (50, 100, 150, 200, and 250 µg/ml) were obtained. By utilising the log dosage inhibition curve, the DPPH free radical was determined. An increase in free radical activity was demonstrated by a decrease in the absorbance of the reaction mixture. We found that at 250 µg/ml, the inhibition was at its peak, at 78%. When compared to the control, ascorbic acid, a commonly used antioxidant medication, demonstrated a maximal inhibition of 69% at a dosage of 100 µg/ml. H_2O_2 scavenging was used to evaluate the free radical scavenging capabilities of methanol extract and ascorbic acid at various doses. These findings proved that the extract effectively scavenged free radicals. Various concentrations of solutions (50, 100, 150, 200,

and 250 µg/ml) were measured at 517 nm. By utilising the log dosage inhibition curve, hydrogen peroxide scavenging activity was determined. An increase in free radical activity was demonstrated by a reduction in the reaction mixture's absorbance at 250 µg/ml; the highest level of inhibition (80%) was noted. At a dosage of 100 µg/ml, the antioxidant ascorbic acid showed a maximal inhibition of 68% compared to the control[81-82].

1.6.7 Wound Healing Activity

Researchers found that compared to the control (simple ointment), ointment containing *Eichhornia crassipes* extract at varying doses considerably improved the wound contraction ability. Similar to the animals treated with nitrofurazone ointment, those on the fourth day, the group treated with a 15% w/w extract ointment showed a significant improvement in wound healing. Wound contraction rate and time to closure were both considerably higher in the group that used the 15% w/w extract ointment. Similar to the group given nitrofurazone ointment, the 18th day saw 100% contraction. The animals in the 10% w/w extract ointment group began to exhibit substantial wound contraction on day 18 and continued to do so until day 20, when the wound had closed completely. It shows that *E. crassipes* leaf extract, which is 50% methanolic, has the potential to promote wound healing[83-85].

1.6.8 Antitumor Activity

A 50% methanolic extract of *Eichhornia crassipes* exhibited anticancer action, which showed that tumour volume increased slowly and steadily but showed a dramatic swing in size between days 6 and 10. Radiation and tumour test groups showed a reduction in tumour growth compared to the control group. The anticancer efficacy of *E. crassipes* leaf extracts was observed against T47D, PC3, NCI-H322, and A549 cell lines. The AQ fraction of *E. crassipes* leaf exhibited a cytotoxic capability of 44% and 51% against the NCI-H322 cell line, respectively. T47D cell line samples exhibited cytotoxic activity ranging from 20% to 31%. The extracts tested were ineffective against the PC3 and A549 cell lines. Various test cell lines showed cytotoxic activity ranging from 50 to 62% when exposed to standard anticancer medicines at varying doses[86-89].

1.6.9 Anti-inflammatory Effects

For a long time, people have turned to the stems and leaves of *Eichhornia crassipes* for relief from swelling and wounds. This is because the phenolic content of the plant has anti-inflammatory benefits. Examining the ethyl acetate extract of *E. crassipes* provided the strongest anti-inflammatory impact on paw oedema caused by formaldehyde *in vivo*, despite extracts from the plant's leaves and shoots made of petroleum ether and water also having an impact. Paw oedema decreased by 67.5%. Researchers link this anti-inflammatory impact to the presence of phenolic compounds and anthocyanins[90,91].

1.6.10 Hepatoprotective Effects

The root and flower have long been used in Bangladesh to alleviate stomach bloating and liver problems. To find out whether a methanol extract of the protected rats' liver against hepatotoxicity caused by carbon tetrachloride. *E. crassipes* has shown promise as a hepatoprotective agent due to its effects on liver indicators *in vivo* and its capacity to combat oxidative stress. When given to rats alongside isoniazid, the aqueous extract of the leaves reduced malondialdehyde levels by 46% and increased the total antioxidant value of plasma by 21%. Aqueous water hyacinth extract improved serum hepatic marker levels, including alkaline phosphatase (69.22%), SGOT (29%), SGPT (62. *E. crassipes* 31%), creatinine (108.80%), total bilirubin (48.95%), and haemoglobin (65.69%) leaves at a dose of 400 mg/kg[92,93].

2. Biological Activities

2.1 Larvicidal Activity

In addition to the possible toxicity of acetone extracts against two pests, it was discovered that hydrolysed leaf extracts, when tested against chironomid eggs and larvae, *E. crassipes* crude ethyl acetate, hexane, and methanol proved to be effective. *Achaea janata* demonstrated strong larvicidal activity (LD_{50} > 100 mg/m1), while *Spodoptera litura* (Fab.) demonstrated strong larvicidal activity (LD_{50} = 93 mg/m1). In comparison to other solvent extracts, ethanol extracts from *E. crassipes* leaves and buds had greater larvicidal activity against *Culex quinquefasciatus* (LC_{50} = 71.43, 94.68, 120.42, and 152.15 ppm). The presence of

metabolites such as anthraquinones, alkaloids, and flavonoids may be the cause of this behaviour. It has been found that sitosterols and steroids have larvicidal properties. Furthermore, the effects of plant injections on mosquito attraction and oviposition stimulation were investigated; the findings indicate that plants produce volatile compounds such as terpenoids and derivatives of fatty acids[94].

2.2 Allelopathic Effects

Eichhornia crassipes has been found to exhibit pronounced allelopathic effects on a variety of aquatic plants. Extracts from sterile cultures of *E. crassipes* were tested for inhibition of *Chlamydomonas reinhardtii*. At low concentration, the extract did not inhibit *C. reinhardtii* growth. However, inhibition increased with increasing 100 µl of the extract, exhibiting complete inhibition, indicating a high concentration of the same. Researchers looked at the phytotoxic effects of sterols extracted from plants using ethyl acetate on the root development of radishes. The inhibition of radish root elongation at 6 µmol by 4α-methyl-5α-ergosta-8,24(28)-diene-3β,4β-diol is 40% and 30%, respectively. We tested the allelopathic effects of the plant extract against the rapid germination of *Mimosa pigra* and *Vigna radiata*, as well as the phytotoxicity of the leaf extract of *E. crassipes* against these invasive weeds and plants[95].

2.3 Insecticidal Activity

At 2% concentration, it was discovered that both methanol and n-hexane extracts of water hyacinth had antifeedant potential; the methanol extracts were 35.9% and the hexane extracts were 57.8% for tobacco larvae. The presence of terpenoids may be associated with this behaviour[96].

2.4 Immunostimulatory Effects

Eichhornia crassipes has been investigated as an immunostimulatory agent to guard against aquaculture-related bacterial, fungal, and viral illnesses. According to Chang *et al.*, the prawn *Macrobrachium rosenbergii* immunological response and resistance to *Lactococcus gravidae* were improved by 39.1% and 52.2%, respectively, by 2 and 3 g/kg of plant extract. Additionally, as an immunostimulant against *Lactococcus gravidae*, the prawn *M. rosenbergii* was fed a variety of strategies that included an aqueous extract of *E. crassipes* leaves. Therefore, the long-term use of plant infusions is being considered (2–20 g/kg), enhancing pathogen resistance by 68.5% and innate immunity by 88.4%[97].

2.5 Pet Food Formula

Protein, vitamins, and minerals are abundant in *Eichhornia crassipes*. Thailand, China, the Philippines, and Indonesia utilise the plant as a high-quality raw material for fisheries, poultry, and non-ruminant animals. Animals often consume plant biomass in the form of feed, herbage, or as an additive to sugar cane, molasses, grain straw, or other dietary supplements. *E. crassipes* has a wide variety of biological activities, which have been attributed to the existence of bioactive compounds from many families of secondary metabolites[98].

2.6 Patents Including *Eichhornia crassipes* (Mart.) Solms

Numerous inventions involving *E. crassipes* (Mart.) have sought possible methods to turn it into high-value goods. These patents highlighted the value of weeds in medicine and their potential to yield novel treatments. They also documented the application of various plant parts for anti-ageing, antioxidant, antibacterial, anti-inflammatory, and other purposes. Numerous patents in the literature on *E. crassipes* (Mart.) reveal how the plant is used in the cosmetics sector, mixing classic recipes with cutting-edge extraction methods to create powerful results. Methods for creating herbal cream and hand cream were developed by Cui and Wang, respectively. Plant-based hand creams can aid in the healing of secondary infections while receiving therapy. The cream reduces inflammation, itching, and oedema by interacting with the immune system. According to Cui, the herbal cream effectively prevents bacterial and fungal skin diseases. It is manufactured from *E. crassipes* and other herbal medications utilising current technology. Additionally, Leconte and Rossignol-Castera present a technique for creating innovative cosmetic formulations that use a lipophilic extract of water hyacinth to moisturise, maintain, and restore skin hydration. The application of *E. crassipes* in pharmacology and medicine is the subject of another invention. Yu *et al.*, presented a pharmacological

Table 5. Patents related to *Eichhornia crassipes* published between 2010 and 2025[101]

Patent Number	Publication Date	Title	Description of the Invention
CN104224601	2013-03-26	Whitening and freckle removing sunscreening gel	The present invention relates to sunscreen whitening and freckle removal gels using various botanical formulations containing water hyacinth extracts. Sunscreen whitening and freckle removal gel is mainly used to prevent the production of melanin, achieve sunscreen, whitening, and freckle removal effects, prevent skin from suntan and sunburn, and keep the skin youthful.
EP2777709B1	2014-09-17	Applying a water hyacinth lipophilic extract as a skin moisturiser.	To keep and revive skin's moisture, a novel cosmetic formulation based on lipophilic extracts has been developed.
CN104415177A	2015-03-18	Hand cream with water hyacinth	In the event of a subsequent infection, using hand lotion while receiving treatment might speed up the healing process. In conjunction with the immune system, the cream reduces swelling, irritation, and inflammation, and it is easily absorbed by the human body.
IN3297/CHE/2013	2015-01-30	Cosmetics derived from the innovative photoprotective cinnamate of *E. crassipes* (Mart.) Solm.	Identifying new photoprotective chemicals in water hyacinth and developing sunscreens that include these components for optimal UV protection.
CN104940559	2015-09-30	Methods for preparing an external lotion based on traditional Chinese medicine for the treatment of pediatric urticaria	A topical lotion including herbs for the treatment of urticaria in children is described in the current invention. Water hyacinth and other crude pharmaceuticals are the basis for herbal remedies used topically. The lotion's benefits include a low recurrence rate, a quick action, few negative effects, and the ability to repel the wind while also easing itching, breaking the crust, and eliminating heat.
CN104415178A	2015-03-18	Herbal cream made from *E. crassipes*	Using cutting-edge manufacturing techniques, the herbal lotion is formulated using *Eichhornia crassipes* and other medicinal herbs. Active compounds abound in the cream. Because of its powerful penetration, it is safe for use by individuals of all ages. Applied externally to the skin. Suitable for the prevention of skin infections caused by fungi and Gram-positive bacteria.
CN104414960A	2015-03-18	*E. crassipes* conditioning cream for dermatitis	The nourishing cream is based on the use of water hyacinth extract and other plants. This cream removes heat and penetrates the skin quickly to help relieve symptoms such as redness, swelling, pain, localised erythema, and peeling skin.
CN105055690A	2015-11-18	Preparation and novel application of *E. crassipes* extract	Different doses (0.5-1.5 g/kg) of the water extract of *Eichhornia crassipes* showed a stress on the exercise performance of mice. At low doses of the water extract, significant regulatory and controlling effects were observed with the enhancement of physical performance. However, ingestion of high doses of plant extracts had a pronounced modulating and controlling effect on Locomotion speed.
CN104415179A	2015-03-18	*E. crassipes* dropping liquid for onychomycosis	The water hyacinth infusion composition is effective and helps patients get rid of the discomfort of onychomycosis.

Table 5. Continued...

Patent Number	Publication Date	Title	Description of the Invention
CN104414899	2015-03-18	*E.crassipes* for the treatment of acne and comedones.	Products made from water hyacinth extract, along with other botanical herbs and sophisticated technologies, are used to make the cream. The microcirculation of the human body can be improved by botanical lotions, which also have the function of removing heat, fire, moisture, inflammation, and bacteria.
CN104415327	2015-03-18	A natural gargle made with *E. crassipes*	An herbal mouthwash is a unique concoction of the medicinal properties of plants, such as Assorted botanicals, including *Eichhornia crassipes*. For the most part, people use herbal gargles to get rid of bad breath, mouth bacteria, and the risk of dental disorders. Everyone can benefit from herbal gargles because of how effective they are against bacteria.
EP2777709A1	2016-01-13	Using a lipid-soluble *E. crassipes* extract to hydrate the skin	Lipophilic extracts of *Eichhornia crassipes* are used in cosmetics to keep or restore the skin's moisture levels.
EP3068496B1	2017-11-08	Made with oil from the lipophilic extracts of *E. crassipes* and China rose	Novel oleaginous compositions based on lipophilic extracts of *Eichhornia crassipes* and China rose for increasing skin brightness are the subject of the present invention.
KR101917740B1	2018-11-13	A cosmetic product that includes *E. crassipes* extracts	Water hyacinth extract is an active component in the cosmetic formula that helps with anti-inflammatory, skin moisturising, wrinkle improvement, and antioxidant properties.
WO2018105799A1	2018-06-14	A cosmetic product whose main ingredient is an extract from *E. crassipes*	Water hyacinth extract is an active component in cosmetic formulations due to its anti-inflammatory, skin-soothing, antioxidant, and nutritive properties, which have anti-wrinkle or hydrating characteristics. This results in a remarkable enhancement of the skin's quality, particularly with regard to the reduction of wrinkles.
CN110585879A	2019-12-20	An all-natural deodorant made from *E. crassipes* and the process for making it	A natural deodorant made from water hyacinth that can be mass-produced for agricultural use.
CN107312104B	2020-04-21	Method for preparing alkyl polyglycoside from *E. crassipes* Polysaccharide	In order to synthesise alkyl, the current invention uses water hyacinth to extract polysaccharides and polyglycolides that provide effective antifoaming and emulsifying capabilities.
CN112076237A	2020-12-15	Triterpenoids from *E. crassipes*: Extraction, optimisation, and potential uses	Using water hyacinth as a starting point, this method enhances the extraction of triterpenoids. Consequently, the anti-inflammatory activity and antioxidant capacity of the industrially valuable extract are enhanced, and the yield of triterpenoids is improved, using the Box-Behnken response surface methodology.
CN111184801A	2020-05-22	Method for preparing the total flavonoids of the leaves of *E. crassipes*	The present invention relates to the extraction of all flavonoids from plant leaves using homogenised ultrasound. The present invention has the advantage of being fast and efficient, using small amounts of solvent with good reproducibility.

Table 6. Value-added chemicals produced from *Eichhornia crassipes* and their applications[102]

Products	Process	Applications
Furfurals and hydroxy methyl furfural	Chemical and thermal pretreatment of lignocellulosic biomass with Non-hazardous oxidant (Ferric trichloride)	Bio-refinery products, petroleum derivatives
Cellulose xanthogenate	Extraction with Sodium hydroxide and Carbon disulfide	Increases the adsorption of heavy metals
Hydrogel	Polyvinyl alcohol + glutaraldehyde	Biopolymer (Controlled Release Technology)
Polyhydroxybutyrate	Alkaline, peracetic acid pretreatment and	Biodegradable bioplastic used in food packaging, medical devices (implants, scaffolds), and drug delivery, due to its biodegradability, biocompatibility,

Table 7. Enzymes produced from *Eichhornia crassipes* residue[103-107]

Enzymes	Applications	Microorganisms	Process
Cellulase	Food, textiles, and the paper industry	*Trichoderma reesei*	Fermentation
		Aspergillus niger Trichoderma viride	Submerged fermentation
		Aspergillus niger	Physical and biophysical pretreatment + fermentation
β-glucosidase	Key enzyme in the final step in hydrolysis of cellulose by converting cellobiose to glucose	*Rhizopus oryzae*	Solid-state fermentation
Xylanase	Paper industries, additives in animal feedstock, food additives, ingredients in detergents, fabric care compositions, and biofuel production	*Trichoderma reesei*	Pretreatment + fermentation
		Trichoderma species	Fermentation

composition suitable for treating inflammation. They stated that triterpenoids have a high industrialisation value and enhanced anti-inflammatory and antioxidant properties[99,100]. Table 5 represents the patents of *E. crassipes* published between 2010 and 2025.

2.7 Neuroprotective Mechanism of *Eichhornia crassipes*

Phytochemicals found in water hyacinth, *E. crassipes*, include glycosides, phenolic compounds, alkaloids, tannins, saponins, and sterols; these compounds are recognised for their antioxidant and neuropharmacological properties. Tables 6 and 7 represent enzymes produced from *E. crassipes* residue and value-added chemicals produced. An antioxidant defence system is at the heart of the neuroprotective mechanisms. Strong cytoprotection was shown in *in vitro* tests using its ethanolic floral extract: by increasing cell viability, decreasing lipid peroxidation (as measured by malondialdehyde), decreasing LDH leakage, and increasing activity of catalase and reduced glutathione, pretreatment prevented H_2O_2-produced oxidative damage. It's likely that this antioxidant action also extends to neuronal cells. The extract stabilises cell membranes and shields neurons from oxidative stress, which is a known cause of neurodegenerative damage. It does this through scavenging reactive oxygen species (ROS) via both enzymatic and non-enzymatic pathways, such as glutathione (GSH) and phenolics. *In vivo* neuropharmacological research has supported the effects on the central nervous system (CNS), including sedation, anti-anxiety, antidepressant, and memory enhancement. Ethanol extracts, either alone or in combination with *Nelumbo nucifera*, significantly

reduced writhing, anxiety-like behaviour, and motor activity, according to the results. Additionally, treated brains exhibited histological indicators of neuronal protection, such as glial responses, and slept longer. Below, you will discover multiple assertions.

1. Phytochemicals present → phenolics, flavonoids, alkaloids, etc.
2. Scavenge ROS/reduce oxidative stress → via increasing catalase, GSH
3. Stabilise neuronal membranes and improve viability → prevents peroxidation and leakage
4. Behavioural CNS effects → sedative, anxiolytic, memory-supportive changes observed in animal models. Overall, *E. crassipes* extracts show promise as neuroprotective agents due to their combination of antioxidative and neuropharmacological effects, which calls for additional investigation into their therapeutic uses[108].

3. Conclusion

To shed light on the chemical makeup of *E. crassipes* and its potential for value-added applications, this in-depth analysis of the plant's phytochemical composition, pharmacological and biological activities, and global medicinal uses is being conducted. In this review, unique plant phytoconstituents are outlined for various applications. Multiple phytochemical investigations have relied on the separation and identification of secondary metabolites, including polyphenols, flavonoids, sterols, alkaloids, and others, from plants. The primary chemicals, phytosterols and terpenoids, can be used to supply the food and pharmaceutical sectors with molecules that enhance their value. Furthermore, furfural, xylitol, enzymes, polymers, and composites are some of the value-added products that have been produced from *E. crassipes* biomass using physicochemical processes. These compounds have found usage in a range of applications. Along these lines, it would be intriguing to investigate various approaches to industrial-scale by-product production using integrated processes. Furthermore, *E. crassipes*'s biological and pharmacological characteristics have been the subject of much debate. There is some evidence that plant extracts and bioactive chemicals may have anticancer effects when tested on different types of cancer cells. Furthermore, *E. crassipes* extract has antimicrobial, antioxidant, antifungal, and anti-inflammatory properties, as shown in multiple research studies. Furthermore, additional research is required before the plant can be used in therapeutic settings, even if multiple patents detail its pharmacological effects. The majority of research on *E. crassipes*'s possible health impacts has been conducted on animals; therefore, any pharmacological findings must have underlying mechanisms. Evidence from other research suggests that *E. crassipes* extract can aid in the healing of wounds. There may be anti-ageing benefits to using botanicals. To standardise and validate botanicals as anti-ageing agents, new formulations are being developed in related domains. Plants should, however, pay greater attention to the separation of bioactive chemicals. As a result, future research should focus on elucidating the toxicity of the compounds and providing greater clarification on their efficacy. The study's inherent shortcomings, such as a small sample size and low quality, were unavoidable. *E. crassipes* may already be a valuable medicinal herb, but further research might make it much more so in the future. To help develop and use this precious resource in the pharmaceutical sector, research into the toxicological and pharmacological processes of plants is necessary, as is the establishment of an efficient scoring system.

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Author Contribution

M. K.: Writing - review and editing. A. D.: Investigation, review, and editing. N. G.: Supervision. A. D.: Revision of manuscript. All authors have read and agreed to the published version of the manuscript.