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Eicchornia crassipes: Not As Bad As It Seems

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ABSTRACT:
Background: Water hyacinth, also known as Eichhornia crassipes, is one of the world's most invasive aquatic macrophyte weeds and a member of the family Pontederiaceae. It is found in tropical and subtropical regions of the world. Although water hyacinth is considered a troublesome weed, it poses serious ecological problems such as significant loss of water resources. It has multiple multi-purpose uses. It has many socioeconomic uses, such as remediation of industrial wastewater, a bioenergy source, used in biofertilizer production, and animal feed. **The main body of the abstract:**Water hyacinth is rich in various bioactive plant components such as alkaloids, sterols, phenols, flavonoids, tannins, phenalenones, and saponins. These secondary metabolites are known to have a wide range of therapeutic properties. It exhibits various pharmacological activities such as antitumor, antioxidant, anti-inflammatory, antibacterial, neuroprotective, and hepatoprotective. Many inventions made in Eicchornia crassipes (Mart.) have attempted to find potential ways to make high-value products out of it. Emphasizing the importance of weeds in medicine, and as a source of new remedies, these patents also published the use of different parts of the plant for different uses like anti-aging, antioxidant, antibacterial, anti-inflammatory and many more.
Short conclusion: A lot of research has been done on the pharmacologically active plant constituents of Eicchornia crassipes (Mart.) plant. Still, many pharmacological activities of this medicinal weed have to be carried out. The current review comprehensively summarizes the previously reported chemical composition of Eicchornia crassipes and its traditional uses and pharmacological and biological activities.

KEYWORDS: Eichhornia crassipes (mart.) Solms, Phytoconstituents, Pharmacology activities, Biologicalactivities, Macrophytic weed

I. INTRODUCTION:

Water hyacinth, also known as Eichhornia crassipes(Mart.), is a monocotyledonous plant belonging to the family Pontederiaceae, a large free-floating aquatic weed. This weed is native to Brazil and the Amazon, but is also found in many tropical and subtropical regions, including India, Australia, Africa, Egypt, Sudan, Kenya, Ethiopia, Nigeria, Zimbabwe, Zambia, and South Africa[1]. Plants are mainly characterized by rapid and rapid growth with wide distribution, strong tolerance to pH, nutrient fluctuations and temperature conditions. As such, it has been recognized by the International Union for Conservation of Nature as one of the 100 most aggressive invasive species and identified as one of the 10 worst weedy plants in the world [2,3,4], however, there are many potential advantages. It is known for its phytoremediation properties useful in wastewater treatment as it absorbs heavy metals and grows in polluted water [5,6]. It is also considered as a potential source of bioenergy [7]and biofertilizer[8]. Traditional uses of the plant include treating gastrointestinal disorders such as intestinal parasites, indigestion, diarrhea and gas. The plant is a rich in diverse bioactive plant constituents that exhibits a wide range of pharmacological and biological activities. Some of these are antioxidants [9], antimicrobials [10,11], antitumor agents [12], anticancer agents[13,14], anti-inflammatory [15], hepatoprotective [16], larvicidal [17], wound healing[18]. To date, many patents have been filed, mainly in the field of medicinal uses of plants and their product formulations. The current review study thoroughly evaluates water hyacinth phytochemical composition, therapeutic uses and properties relevant to pharmaceutical applications, as well as patents filed on the plant.

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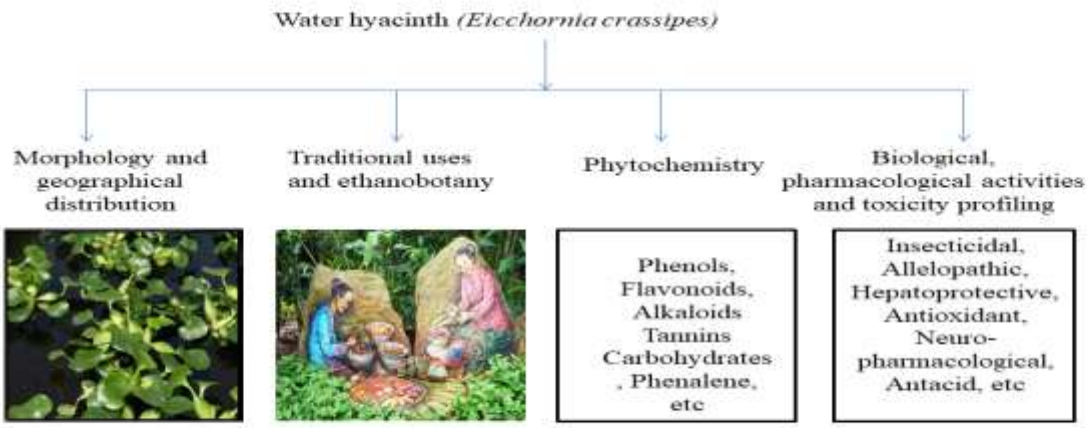

Pharmacognostical and pharmacological importance of Eicchornia crassipes

1. Plant Description[19,20]:

1.1. Biological source:It consists of free floating perennial aquatic plant of Eichhornia crassipes (Mart.)

1.2. Family: Pontederiaceae

1.3. Scientific name: Eichhornia crassipes (Martius) Solms-Laubach

1.4. Synonyms: Pontederia crassipes Martius; Eichhornia speciosa Kunth; Pontederia azurea Hook; Pontederia azurea Roem. & Schultes; Eichhornia cordifolia Gandoger

1.5. Common names in the various regions of the world: Aguapé, Jaronesa (Brazil), Jacinto-aquatico (Portugal), Bisnidh, Zanim, zoqqueym ettani Baqaqa, Habba, Halassandi/halassant (Egypt), Buchón (Colombia), Bora (Venezuela), Jacinthe d'eau (France), Gulbakauli (Pakistan), Jacinto de agua o camalote, lechuguilla, lirio acuatico (Spain), Lila de agua (Dominican Republic), Tokozelka (former Czechoslovakia), Top-chawa (Thailand), Violeta de agua (Chile), Wampee (former USSR), Wasserhyazinthe (Germany), Su sümbülü (Turkey), Tarulla (Colombia), Vanhyacint (Denmark), Water hyacinth (United Kingdom and India), Yakinton hamaim (Israel)

1.6. Vernacular Names of Eichhornia crassipesin India:

Hindi: Jal kumbhi
English: Water hyacinth
Kannada: Antara taavare, Antarangange
Manipuri: Kabokkang
Mizo: Dum-awr-puar
Sanskrit: Jalakumbhi, Variparni
Telugu: Budaga Tamara, Gurra pudekka moka
Tamil: Venkayattamarai

1.7. Taxonomy of Eichhornia crassipes:

Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Monocotyledonae
Order: Pontederiales
Family: Pontederiaceae
Genus: Eichhornia
Species: Eichhornia crassipes

1.8. Geographical Distribution: Eicchornia crassipes is distributed throughout the world, flourishing in tropical and subtropical regions. EPPO region: Israel, Italy, Jordan, Portugal, Spain Asia: Bangladesh, Cambodia, China, Brunei Darussalam, India, Indonesia, Lebanon, Japan, Laos, Malaysia, Maldives, Myanmar, Philippines, Singapore, South Korea, Sri Lanka, Syria, Taiwan, Thailand, Vietnam. North America: Mexico, USA (Alabama, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, Texas).

1.9. Phenology:

Flowering: May to December
Fruiting: July to December

1.10. Habitat: Water hyacinth is a free floating weed of tropical and sub-tropical freshwater lakes and rivers; especially those enriched with plant nutrients

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1.11. Morphological Characteristics:

Leaves: Thick, waxy, round, broad, 10-20 cm (4-8 in) in diameter, cuplike, glossy, green in color. **Stems**: Spongy; erect; stems up to 50 cm (20 in) long; inflated with air bladders towards the base. **Flowers**: Showy, lavender-blue in color, 6 petals, upper petals with a central, yellow blotch; 8-15 flowers occur on a single spike that can be up to 30 cm long; bloom mid-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.

Fig. (1).Plant of Eichhornia crassipesshowing spongy stalk and stem[19]

Fig. (2).Flowers of Eichhornia crassipes[19]

Fig. (3). Roots of Eichhornia crassipes[19]

Fig. (4). Plant of Eichhornia crassipes[19]

Fig. (5). Petioles of Eichhornia crassipes[19]

Fig.(6). Seeds of Eichhornia crassipes[19]

1.12. Useful Part: Whole plant

2. Phytoconstituents And Phytochemistry:

The phytochemical composition of water hyacinth has been widely evaluated which reveals diverse secondary metabolites, among them polyphenols, flavonoids, fatty acids, alkaloids, sterols and other primary metabolites like different types of carbohydrates such as L-galactose, L-arabinose, and D-xylose [21,22,23]as well as hemicellulose, cellulose, glycolipids, and triacylglycerol's[24], proteins and phospholipids such as Phosphatidylethanolamine, phosphatidyl choline and phosphatidylglycerol identified in the flowers, leaves, stalks, and roots [25]. The leaves contain various amino acids like leucine, asparagine, and glutamine [26]. Two fractions of peptides have been identified from the leaves as Glu-Leu-Phe and Phe-Phe-Glu [27]. The chemical composition of waterhyacinth from different geographic regions is found to be vary[21].

2.1. PhenolicCompounds:

Pyrogallol, 4-methylresorcinol, catechol, 2-methylresorcinol and resorcinol were found to be present in different concentration in different parts of the plant. Also, many phenolic acids were detected in different types of extracts of the leaves, petioles, and flowers of Eicchornia crassipes. They are represented by p-hydroxybenzoic, gentisic, chlorogenic, caffeic, p-coumaric, ferulic, vanillic, syringic, gallic, protocatechuic and salicylic acids [28,29]. The ethanolic extract of flowers contained higher levels of gentisic, protocatechuic acids, and p-hydroxybenzoic acid as compared to the petioles and leaves[29].

2.2. Flavonoids:

Flavonoids and their glycosides are abundantly present in different extracts of water hyacinth[27,29]. Anacylateddelphinidinglycosiderepresentedby 6‴-O-{delphinidin-3-O-[6‴-O-(β-d-gluco pyranosyl)]}, {6‴-O-[apigenin- 7-O-(β-d-glucopyranosyl)]}malonatewereisolatedfromtheflowers[30]. The water andpet ether extracts of the rhizome and shoot were characterizedby the presence of gossypetin, tricin, azaleatin,chrysoeriol, luteolin, apigenin and in addition orientin, kaempferol, quercetin, and isovitexinwere also identified from the roots and shoots [27,29,31]. From theleavesandpetiole of water hyacinth Naringenin,kaempferol,myricetinandrutin werereported[32]. Recently, Quercetin7-methyletherwas also isolatedfromtheethanolextractoftheplant[33]. From water hyacinthcollected from Indiaa subgroup of flavonoids have been detected inthe ethanol, acetone, and aqueous extracts of the shoots andleaves parts [29].

2.3. Saponins:

Water hyacinth collected from the Phewa Lake in Nepal showed the presence of saponins in the aqueous extracts [34], contrary to this, aqueous extracts of the plant from Dijla River, Baghdad, showed the absence of saponins[35]. Phytochemical screening of water hyacinth plant samples collected from Nepal revealed the presence of saponins in hexane, chloroform, and ethanol extracts [34,36]. Recently two steroidal saponins, namely spirostane and cholestane were isolated from acetone extract of the roots and cyclohexane extract of leaf of water hyacinth respectively[37].

2.4. Terpenoids:

From water hyacinth collected from India, Phytol was isolated and identified by GC-MS in the ethanol extract of whole plant[38,39]. From plant sample collected from Mexico, Squalene, a hypocholesterolemic terpenoid was identified in the non-polar extracts of the leaves and stems [37]. After conducting GC-MS studies Camarolide, a pentacyclic triterpenoid, in the methanol extract of the aerial parts of the plant was isolated and identified by Lenora et al. 2016.

2.5. QuinonesandAnthraquinones:

The nonpolar extracts of shoot of water hyacinth were reported to contain several quinones like aloe-emodin, 7-methyl-juglone andrheinwhereasaloe-emodinwas alsofoundinthenonpolar extract of rhizome[27].

2.6. FattyAcids:

The GC-MS analysis of the nonpolar extract of leavesof water hyacinthproved the presence of many fatty acids represented by linolenic acid ethyl ester, palmitic acid ethyl ester, α-glyceryl linolenate, E-11- hexadecenoic acid ethyl esterand stearicacid ethyl ester. The GC-MS of the nonpolar extract of petiole part revealed the presence of hexadecanoic acid ethyl ester, palmitic acid ethyl ester, 9,12,15- octadecatrienoic acid ethyl ester and n-hexadecanoic acid [39,40].Different types of extracts from the leaves, stems, and roots of water hyacinth revealed the presence of some fatty acids like linolenic acid, caprylic acid, lauric acid, myristic acid, oleic acid, vaccenic acid, tetracosanoic acid and 10,12-octadecadienoic acid and cis-vaccenic acid[37,41].

2.7. Sterols:

Phytosterols represent 19–23% wt. of the extracts of water hyacinth. 6α-Hydroxystigmata-4,22-dien-3-one,4α-methyl-5α-ergosta-7,24(28)-diene-3β,4β-diol,4α-methy1-5α-ergosta-8,14,24(28)-triene-3β,4β-dioland 4α-methyl-5α-ergosta- 8-24(28)-triene-3β,4β-diol were isolated from the ethyl acetate extract of the plant [42]. β-campesterol, methylcholesterol, β-sitosterol and sitosterol were isolated and identified from the stalk and leaf extracts. Stigmasterol is considered the most common and major phytosterol identified in different parts of water hyacinth[39,43]. β-stigmasterolwas found in hexane, acetone, and methanolic extracts of the leaves and stems [37].

Recently, 22,23- dibromostigmasterol acetate which is a novel derivative of stigmasterol was isolated from the ethanolic extract of the shoots and amounted to 28.72% of the extract [39].

2.8. Alkaloids:

Water hyacinth is considered as a potential source of alkaloids. They represent 0.98% of the crude extract of the plant [44]. Tomatine and Cytosine were predominantly found in the rhizome and shoot. In the Indian species of water hyacinth, shoot revealed the presence of quinine, thebaine and codeine while nicotine is found mainly in the rhizome[45]. In addition, GC-MS analysis of ethanol extract detected the presence of 1H-pyrrole,1-phenyl and pipradrol[44,46]. Furthermore, 18,19-secoyohimban-19- oic acid-16,17,20,21-tetradehydro-16-(hydroxymethyl)-methyl ester (72), di amino-di-nitro-methyl dioctyl phthalate and 9-(2′,2′-dimethyl-propanoilhydrazono)-2,7-bis-[2- (diethylamino)-ethoxy]fluorene were isolated from leaf extract[47,48].

2.9. PhenaleneandPhenylphenaleneDerivatives:

Phenylphenalene derivatives were also isolated and identified from water hyacinth represented by 4,8,9-trimethoxy-1-phenyl-2,3-dihydro-1H-phenalene, 4,8,9-trimethoxy-1-(4 methoxyphenyl)- 2,3-dihydro-1H-phenalene,4,4″,8,8″,9,9″,4′,4‴-octamethoxy-1,1″-diphenyl-2,2″,3,3″-tetrahydro-7,7″-bi(1H-phenalene), 6,6″,8,8″,9,9″,4′,4‴-octamethoxy-1,1″-diphenyl-2,2″,3,3″-tetrahydro-7,7″-bi(1H-phenalene), 4,4″,8,8″,9,9″-hexamethoxy-1,1″-diphenyl-2,2″,3,3″-tetrahydro-7,7″-bi(1H-phenalene),2,3-dihydro-8-methoxy-9-phenyl-1H-phenalene-1,4-diol,methyl-5-methoxy-2-phenyl-8[3,7,10-trimethoxy-6-phenyl-5,6-dihydro-4H-phenaleno(2,1-b)furan-9-yl]-1-naphthoate,2,3-dihydro-4,8-dimethoxy-9-phenyl-1H-phenalen-1-ol,2,3-dihydro-9-(4-hydroxyphenyl)-8-methoxy-1H-phenalene-1,4-diol, together with 2,6-dimethoxy-9-phenyl-1H-phenalen-1-one , 2-hydroxy-9-(4-hydroxyphenyl)-1H-phenalen-1-one and 2,3-dihydro-3,9-dihydroxy-5-methoxy-4-phenyl-1H- phenalen-1-one. Moreover, 5,6-dimethoxy-7-phenyl-1H- phenalen-1-one, 2-hydroxy-9-(4-hydroxyphenyl)-1H-phenalen-1-oneand methyl 3-(4-hydroxy 3-methoxyphenyl)prop-2-enoate)were isolated from the ethyl acetate fraction of the whole plant [51,52,53].

2.10. Carbohydrates:

Sucrose, fructose, glucose, xylose, arabinoseand galactose are soluble sugars present in the leaves, along with galactomannan and branched (1→3)-β-D-glucan [54]. Cardiac glycosides were detected in the chloroform and aqueous extracts of the shoots. Roots of the plant revealed the presence of high amount of sulfated polysaccharides [55]. It is found that cellulose xanthate was produced from the chemical treatment of shoot and root biomass of water hyacinth with NaOH and CS_2[56]. Nanocrystalline cellulose was isolated from fibers of water hyacinth after chemical and mechanical treatments [57]. Xylitol, a pentose polyol, used in food and pharmaceutical industries, was also isolated and identified from the plant [58].

2.11. OrganicAcids:

Different types of extracts from the leaves, stem, and roots of the Mexican water hyacinth plant revealed the presence of oxalic acid, nonanoic acid, malonic acid, succinic acid and phthalic acid [37]. While plant species collected from India revealed the presence of propiolic acid in the ethanolic extract of the leaves as a major compound[59].

Lai et al., 2011 reported that levulinic acid extracted with microwave heating techniques was isolated from the dried plant with a yield of 9.43% dry weight. Shikimic acid, an antiviral agent, was isolated from the aerial parts of the plant material with a yield of 0.03–3.25% w/w [60,61,62]. Isoascorbic acid, ascorbic acid and dehydroascorbic acid were present in the shoot extracts[45]. Humic acids, which play an essential role in retaining water and texture soils were also found to be present in several parts of the plant such as the leaves, stems, and roots [63].

3. PharmacologicalAndBiologicalActivities

The broad biological activity of Eicchornia crassipes has been attributed to the presence of bioactive plant components belonging to different classes of secondary metabolites, as previously reported.

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3.1. Neuropharmacological Effects

Analgesic, antiepileptic, sedative, central nervous system depressant, anxiolytic, antipsychotic, antidepressant, and memory-enhancing properties were demonstrated in mouse models by ethanol extraction from leaves of Eicchornia crassipes and Nelumbo nucifera. It is exerted by a combination of objects [70]. The results showed that an ethanol extract of Eicchornia crassipes leaves significantly inhibited motor activity, exhibited high anxiolytic properties, and reduced exploratory behavior patterns in the avoidance test. Treated mice were able to maintain posture for more than 180 seconds. Moreover, the same extract prolonged sleep latency and duration, improved latency, and resulted in the best inhibition of the acetic acid-induced writhing test[21].

3.2. Anti-Inflammatory Effects

Eicchornia crassipes stems and leaves have been used to treat swelling and wounds due to their anti-inflammatory effects related to the plant's phenolic content [71]. Ethyl acetate, petroleum ether, and water extracts of the leaf and shoot parts of the Eicchornia crassipes plant were investigated for their in vivo anti-inflammatory effects in formaldehyde-induced paw edema, and the ethyl acetate extract showed the highest anti-inflammatory effect, showed an effect. 67.5% reduction in paw edema. This anti-inflammatory effect is associated with the presence of anthocyanin and phenolic compounds[21**,** 29].

3.3. Hepatoprotective Effects

In Bangladesh, the root and flower are traditionally used to treat liver disease and abdominal swelling [72]. To investigate that a methanol extract of Eicchornia crassipes exhibited hepatoprotective activity against carbon tetrachloride induced hepatotoxicity in rats. Eicchornia crassipes was shown to have an effective hepatoprotective agent by virtue of its in vivo effect on liver markers and in combating oxidative stress as well, where the coadministration of the leaves aqueous extract with isoniazid in rats exhibited a 46% reduction in malondialdehyde level with concomitant elevation in the total antioxidant value of the plasma (21%). Aqueous extract of leaves of water hyacinth at 400 mg/kg restored the hepatic marker levels in the serum, like alkaline phosphatase (69.22%), SGOT (29%), SGPT (62.31%), creatinine (108.80%), complete bilirubin (48.95%), and hemoglobin (65.69%)[21, 73].

3.4. Antitumor/Cytotoxic Activities

It is investigated that Eicchornia crassipes is known to contain some therapeutic compounds such as alkaloids and terpenoids that display anticancer properties[74]. The antitumor activity of 50% methanolic extract of Eicchornia crassipes at different doses was studied against melanoma tumor bearing hybrid mice showed a good response [13]. The crude methanolic extract of the whole plant also revealed a notable potency against different cell lines like MCF-7, HeLa cells, EACC, and HepG2 cell lines with IC50 values of 1.2 ± 0.2, 1.6 ± 0.5, 6.04 ± 0.5, and 7.6 ± 1.5 μg/ml, respectively, compared to doxorubicin, a standard drug that revealed 0.28 μg/ml for HeLa and 0.42 μg/ml for both MCF-7 and HepG2 cell lines [21, 15].

3.5. Antioxidant Activity

Eicchornia crassipes is a source of many compounds with free radical scavenging activity, including phenolic acids, sterols, terpenoids, and other metabolites with high antioxidant activity [39]. Ethanol extracts from leaves and flowers of water hyacinth exhibited potent ferrous ion chelating activity and free radical scavenging properties by 2,2-diphenyl-1-picrylhydrazyl (DPPH) method [14,75]. The high antioxidant capacity of crude methanol extracts can be explained by the synergistic action of all bioactive compounds [14]. In addition to methanol extracts, leaf n-hexane and carbon tetrachloride extracts and protein hydrolysates isolated from leaves showed radical scavenging activity [76] .

3.6. Antibacterial Activity

Traditionally, water hyacinth was used in Ethiopia to manufacture herbal medicines to treat various types of pathogenic diseases associated with bacterial infections [77]. The presence of saponins in leaves has been studied to make them potential candidates with significant bioactivity as antibacterial agents in the control of staphylococcal infections against bovine methicillin-resistant Staphylococcus aureus (MRSA) [78]. Coagulase-negative staphylococci (CoNS) in rabbits. Hydroalcoholic and aqueous extracts of leaves showed antimicrobial activity against Bordetella bronchiseptica, Proteus vulgaris and Salmonella typhi[17]. Ethanol extracts of water hyacinth buds and leaves were evaluated against two fungi,

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Aspergillus fumigates and Meiothermus ruber, using the disc diffusion method. Aqueous extracts of leaves have been studied to contain active compounds such as chlorogenic acids, alkaloids, flavonoids, sterols, anthocyanins and quinones, and have significantly improved resistance to the shrimp pathogen Lactococcus garvieae[10, 29]. Ethyl acetate extract prepared at 2 mg from stems showed significant antibacterial activity against Staphylococcus aureus and Salmonella typhi (activity index = 0.21 and 0.23, respectively). The same concentration of leaf ethyl acetate extract was only effective against Salmonella typhi with an activity index of 0.24 [79]. The n-butyl alcohol extract can have antibacterial activity (MIC = 16 µg/ml) against some bacteria such as Escherichia coli, Bacillus cereus, Bacillus casei, Bacillus subtilis, and antifungal activity against some pathogens likeAspergillus niger, Aspergillus alternata, Candida gloeosporioides, Candida albicans, and Fusarium solani (minimum inhibitory concentrations were 8–32 µg/ml) [80].

3.7. Wound Healing Activity

Traditionally, this plant is used in Nigeria for skin care applications [81]. An essential extract of water hyacinth leaves has also been studied in combination with turmeric and rice flour to treat eczema. A methanol extract from leaves of Eicchornia crassipes showed significantly improved wound contractility compared to controls due to the presence of phenolic compounds and was therefore formulated as an ointment containing 10% and 15% leaf extract [12]. Methanolic, hydroalcoholic, and ethyl acetate extracts of the plant have also been shown to promote anti-aging effects by inhibiting DNA damage [24].

3.8. Anatacid Activity

Dhokora khar also called as solid alkali which is obtained from aqueous extract of water hyacinth ash consists of a mixture of carbonates, chlorides, sulfates and phosphates of various metals such as potassium, Magnessium, Calcium, Sodium, Iron, Manganase, Zinc, Copper, Nicke,etc. Dokhara khar has traditionaaly been used in Assam for the cure of ailments arising from stomach acidity and indigestion as well as food additive in preparing palatable dishes due to presence of many essential micronutrients [82].

4. Biological Activities

4.1. Larvicidal Activity

Crude ethyl acetate, hexane, methanol and aqueous leaf extracts of Eicchornia crassipes were found to be effective against chironomid eggs and larvae, in addition to the potential toxicity of acetone extracts against two pests, Achaea janata showed potent larvicidal activity (LD50 > 100 mg/m1) and Spodoptera litura (Fab.) (LD50 = 93 mg/m1) [83]. Ethanol extracts from leaves and buds of Eicchornia crassipes showed higher larvicidal activity against Culex quinquefasciatus (LC50 = 71.43, 94.68, 120.42, and 152.15 ppm) compared to other solvent extracts . This activity may be due to the presence of metabolites such as anthraquinones, alkaloids and flavonoids [24]. Sterols and sitosterols have been reported to have larvicidal activity [82]. In addition, the effects of plant injections on mosquito attraction and stimulation of oviposition were studied, and results suggest that plants release volatile chemicals such as terpenoids and fatty acid derivatives[21,84].

Allelopathic Effects

Eicchornia crassipes has been found to exhibit pronounced allelopathic effects on a variety of aquatic plants. Extracts from sterile cultures of Eicchornia crassipes were tested for inhibition of Chlamydomonas reinhardtii. At low concentrations, the extract did not inhibit Chlamydomonas reinhardtii growth. However, inhibition increased with increasing concentration of extract, as 100 µl of extract showed 100% inhibition [85]. It was found that sterols isolated from ethyl acetate extracts of plants were tested for phytotoxic effects on radish root growth. 4α-methyl-5α-ergosta-8,24(28)-diene-3β,4β-diol shows 40 % and 30% inhibition on radish root elongation at 6 µmol [42]. Phytotoxicity of Eicchornia crassipes leaf extract was evaluated against Mimosa pigra (invasive weed) and Vigna radiata (plant species) and allelopathic activity of plant extract against rapid germination of Mimosa pigra and Vigna radiata[86].

4.2. Insecticidal Activity

Methanol and n-hexane extracts of water hyacinth have been found to exhibit an antifeedant potential at 2% concentration, which varied between tobacco larvae, 57.8% for the hexane extract and 35.9% for the methanol extract [87]. This activity may be related to the presence of terpenoids.

4.3. Immunostimulatory Effects

Eicchornia crassipes has been studied for use as an immunostimulatory agent to protect against viral, bacterial and fungal diseases associated with aquaculture. Chang et al. 2013 reported that 2 and 3 g/kg of plant extract enhanced the immune response and resistance of shrimp Macrobrachium rosenbergii against Lactococcus gravieae by 39.1% and 52.2%, respectively. In addition, different strategies using an aqueous extract of leaves of Eicchornia crassipeswere incorporated into the shrimp Macrobrachium rosenbergii diet as an immunostimulant against Lactococcus gravieae. As a result, long-term administration of plant infusions (2–20 g/kg) increased innate immunity by 88.4% and resistance to pathogens by 68.5% [10].

4.4. Pet Food Formula

Eicchornia crassipes is rich in protein, vitamins and minerals. In Indonesia, China, Philippines, and Thailand the plant is used as a high-quality raw material for non-ruminant animals, poultry, and fisheries. Plant biomass is also commonly used as an herb for cattle, as a feed source, or as a dietary supplement of sugar cane, molasses, and grain straw[21, 79, 88].

The broad spectrum of biological activities of Eicchornia crassipesareat tributed to the presence of bioactive phytoconstituents belonging to different classes of secondary metabolitesas reported earlier.

5. Patents Including Eicchornia crassipes (Mart.)Solms

Many inventions made in Eicchornia crassipes (Mart.) have attempted to find potential ways to make high-value products out of it. Emphasizing the importance of weeds in medicine, and as a source of new remedies, these patents also published the use of different parts of the plant for different uses like anti-aging, antioxidant, antibacterial, anti-inflammatory, etc. Many patents found in the Eicchornia crassipes (Mart.) literature disclose the use of Eicchornia crassipes in the cosmetic industry, combining traditional formulations and using modern extraction techniques to produce potent effects. The inventions of Wang (2015) and Cui (2015) provided methods for formulating hand cream and herbal cream respectively. Hand creams made from plants can promote skin healing of secondary infections during treatment. The cream works with the immune system to eliminate inflammation, relieve itching, and eliminate edema. The herbal cream is made using Eicchornia crassipes along with other herbal medicines using modern technology, but Cui (2015) found this cream to be effective in preventing fungal and bacterial skin infections. Furthermore, the invention of Leconte and Rossignol-Castera (2014) describes a method for preparing novel cosmetic compositions for moisturizing, maintaining and restoring skin hydration using a lipophilic extract of water hyacinth. Another invention relates to the use of Eicchornia crassipes in medicine and pharmacology. Invention of Yu et al. (2020) presented a pharmaceutical composition for use in treating inflammation. They reported that triterpenoids have improved anti-inflammatory activity and antioxidant capacity and have high industrialization value[21].

Table1: Patentsrelated toEicchornia crassipespublishedbetween2010and2020[21].

Patent no	Publication Date	Title	Description of invention
CN104224601	2013-03-26	Whitening and freckle-removing sun-screening 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	Use of a lipophilic	A new moisturizing cosmetic composition based on lipophilic

		extract of water hyacinth for moisturizing the skin.	extracts to maintain and restore skin hydration.
CN104415177 A	2015-03-18	Water hyacianth hand cream	Hand cream can promote skin healing of secondary infections during the treatment period.The cream is easily absorbed by the human body and works with the immune system to eliminate inflammation, relieve itching and remove edema.
IN3297/CHE/2013	2015-01-30	A novel photoprotective cinnamate from Eicchornia crassipes(Mart.)Solms used thereof as photoprotective cosmetic products.	Isolation of novel photoprotective compounds from water hyacinth and sunscreen formulations containing the isolated compounds that provide maximum UV protection capacity.
CN104940559	2015-09-30	Traditional Chinese medicine external lotion for treating urticaria of children and preparation method thereof.	The present invention discloses a herbal topical lotion for treating urticaria in children. Herbal medicines for external use are made from crude drugs such as water hyacinth. The lotion has the effect of repelling the wind, loosening the crust, removing heat, and relieving itching, and has the advantages of high healing effect, fast effect, few side effects, and low recurrence rate.
CN104415178 A	2015-03-18	Eicchornia crassipesherb cream	The herbal cream is made using modern technology using Eicchornia crassipes along with other herbal medicines.The cream is full of active ingredients. Suitable for people of all ages due to its strong penetrating power, it is applied externally to the skin. Suitable for the prevention of skin infections caused by fungi and Gram-positive bacteria.
CN104414960 A	2015-03-18	Eicchornia crassipesconditioning cream for dermatitis	The nourishing cream is based on 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,

			localized erythema, and peeling skin.
CN105055690 A	2015-11-18	Preparation and novel application of Eicchornia crassipeswater extract.	Different doses (0.5-1.5 g/kg) of the water extract of Eicchornia 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 enhancement of physical performance. However, ingestion of high doses of plant extracts had a pronounced modulating and controlling effect on locomotion speed.
CN104415179 A	2015-03-18	Eicchornia crassipesdropping liquid for onychomycosis	The water hyacinth infusion composition is effective and helps patients get rid of the discomfort of onychomycosis.
CN104414899	2015-03-18	Eicchornia crassipescream for comedo and acne removal.	The cream is prepared using water hyacinth extract products, other herbal botanicals and modern technology. Botanical creams have the effect of removing heat, removing fire, removing moisture, removing blood stasis, removing inflammation, preventing bacteria, and can improve the microcirculation of the human body.
CN104415327	2015-03-18	Herbal gargle containing Eicchornia crassipes	Herbal mouthwash is a special formulation of active ingredients of Eicchornia crassipes and other botanicals. Herbal gargles are primarily used to eliminate oral bacteria and bad breath and reduce the incidence of oral diseases. Herbal gargles are highly antibacterial and suitable for everyone.
EP2777709A1	2016-01-13	Use of a lipophilic extract of Eicchornia crassipesfor moisturizing the skin.	Cosmetic compositions composed of lipophilic extracts of Eicchornia crassipes maintain or restore skin hydration through a moisturizing effect.
EP3068496B1	2017-11-08	Oily composition based on lipophilic extracts of china rose and	The present invention relates to novel oleaginous compositions based on lipophilic extracts of china rose and Eicchornia crassipes for improving skin radiance.

		Eicchornia crassipes.	
KR101917740 B1	2018-11-13	Cosmetic composition containing extracts of Eicchornia crassipes.	The cosmetic composition contains the water hyacinth extract as an active ingredient for antioxidant, anti-inflammatory, skin moisturizing or wrinkle improvement.
WO201810579 9A1	2018-06-14	Cosmetic composition containing Eicchornia crassipesextra ct as active ingredient	Cosmetic compositions contain water hyacinth extract as an active ingredient for its antioxidant, anti-inflammatory, skin moisturizing or anti-wrinkle properties. As a result, it has excellent skin improvement effect, especially wrinkle improvement effect.
CN110585879 A	2019-12-20	Pure natural Eicchornia crassipesdeod orant liquid and preparation method thereof	Natural water hyacinth deodorant for industrial mass production.
CN107312104 B	2020-04-21	Method for preparing alkyl polyglycoside from Eicchornia crassipesPolys accharide.	The present invention uses water hyacinth as a raw material for extracting polysaccharides for synthesizing alkyl polyglycosides with good emulsifying and antifoaming properties.
CN112076237 A	2020-12-15	Extraction process, optimization method, and application of triterpenoids in Eicchornia crassipes.	This process uses water hyacinth as raw material and optimizes the triterpenoid extraction process. As a result, the Box-Behnken response surface methodology improves the yield of triterpenoids and enhances the anti-inflammatory activity and antioxidant capacity of the industrially valuable extract.
CN111184801 A	2020-05-22	Preparation method of Eicchornia crassipesleaf total flavonoids.	The present invention relates to the extraction of all flavonoids from plant leaves using homogenized ultrasound. The present invention has the advantage of being fast and efficient using small amounts of solvent with good reproducibility.

6. Augmented Products From Eicchornia crassipes(Mart.) Solms

The Eicchornia crassipes biomass biorefinery has revealed several enzymes and valuable products. Furfural and hydroxymethylfurfural were produced by the ferric chloride oxidation method with the highest yield of 7.9% w/w plant dry matter [93,94]. Eicchornia crassipes is considered a cheap source of fiber production due to its ready availability, low price and high cellulose content. Due to its abundance of cellulose fibers, this plant is used in the production of superconductors and supercapacitors [20, 95].According to several studies, Eicchornia crassipes has been used as a raw material to produce high-value chemicals such as furfural, enzymes, biopolymers and composites as reviewed in Sindhu et al. (2017), Guna et al. (2017), and Ilo et al. (2020) [20,96,97].

Table 2.Value added chemicals produced from Eicchornia crassipesand their applications[21]

Products	Process	Applications	References
Furfurals and hydroxymethylfurfural	Chemical and thermal pretreatment on lignocellulosic biomass with Nonhazardous oxidant (Ferric trichloride)	Bio-refinery products, petroleum derivatives	[93, 94]
Cellulose xanthogenate	Extr action with Sodiumhydroxide and Carbon disulphide	Increases adsorption of heavy metals	[98, 99]
Hydrogel	Polyvinyl alcohol + glutaraldehyde	Biopolymer (Controlled Release Technology)	[100, 101]
Polyhydroxybutyrate	Alkaline, peracetic acid pretreatment and enzymatic saccharification (by Ralstonia eutropha ATCC 17699)	B Biopolymer: the most Important biodegradable plastics	[102]
Carbon fiber	Water hyacinth liquid tar	Precursor for the preparation of composite materials	[103]
Nanocrystalline cellulose	Chemical and mechanical treatments	Potential application in various fields, especially as a reinforcing agent in bionanocomposites	[57]
Laccase	Solid state fermentation by Pycnoporus sanguineus SYBC-L1	Application in harsh industry	[104]
Biopolymer composites	Extraction of water hyacinth fibers + tapioca powder	Mechanical and thermal properties. Thermal resistance and the lowest moisture absorption	[105, 106]
Water hyacinth composite/ NiO composite	Carbonization of water hyacinth + hydrothermal route	Electrode materials for supercapacitors	[107]

Bionanocomposite	Ultrasonic vibration during gelation	Bioplastic	[95, 108, 109]
Supercapacitor electrodes	Energy-saving hydrothermal carbonization	Functional carbon materials	[110]
Polymer nanocomposite	Acrylic acid + nano-hydroxyapatite (nano-HA)	Potential agricultural application	[111]

Table 3:Enzymes produced from Eicchornia crassipesresidue[21].

Enzymes	Applications	Microorganisms	Process	References
Cellulase	Food, textiles, and paper industry	Trichoderma reesei	Fermentation	[112, 113]
		Aspergillus niger Trichoderma viride	Submerged fermentation	[114]
		Aspergillus niger	Physical and biophysical pretreatment + fermentation	[115, 116]
β-glucosidase	Key enzyme in the final step in hydrolysis of cellulose by converting cellobiose to glucose	Rhizopus oryzae	Solid state fermentation	[117]
Xylanase	Paper industries, additive in animal feedstock, food additives, ingredient in detergents, fabric care compositions, and biofuel production	Trichoderma reesei	Pretreatment + fermentation	[113, 118]
		Trichoderma species	Fermentation	[118, 119, 119, 120, 121, 122]

II. CONCLUSION:

This comprehensive review of the plant's phytochemical composition and pharmacological andbiological activities aims to highlight the plant's potential to enhance its limited medicinal uses worldwide, with the aim of highlighting the chemical composition of Eicchornia crassipes and value-added applications.Different phytoconstituent components of the plant are identified for different uses in this review. The results of several phytochemical studies are based on the isolation and identification of various plant constituents such as polyphenols, flavonoids, sterols, alkaloids and other secondary metabolites.Phytosterols and terpenoids, which are considered the main compounds, can be used to provide value-added compounds to the food and pharmaceutical industries. In addition, physico-chemical processes have been used to produce other value-added products from Eicchornia crassipes biomass, such as furfural, xylitol, enzymes, polymers, and composites, and have been applied in various application areas. In this line, it would be interesting to study different strategies to produce by-products on an industrial scale using combined processes.In addition, the pharmacological and biological properties of Eicchornia crassipes have been widely discussed. Various extracts and bioactive compounds isolated from plants have shown anticancer potential against various cancer cell lines. Additionally, various studies have demonstrated the anti-inflammatory, antioxidant, antibacterial, and antifungal activities of Eicchornia crassipes extract. Additionally, although several patents describe the plant's pharmacological effects, clinical applications are still rare and need to be further evaluated. As most of the studies reporting potential health effects of Eicchornia crassipes are animal studies, pharmacological findings must be supported by mechanisms. Other studies have shown the use of Eicchornia crassipes extract in wound healing. Botanicals have shown potential effects in anti-aging. Recent innovations aim to develop new formulations in related fields to standardize and validate botanicals as anti-aging agents. However, plants need to pay more attention to the segregation of bioactive compounds involved in bioactivity. Therefore, it is important to further clarify the potency of the compounds and elucidate their toxicity for future studies.Undoubtedly, quality limitations and a limited number of included studies were inevitable in this study. At the same time, new insights may increase the therapeutic importance of Eicchornia crassipes now and facilitate its future use in modern medicine. Furthermore, there is a need to study the pharmacological and toxicological mechanisms of plants and establish an effective scoring system that can facilitate the development and application of this valuable resource in the pharmaceutical industry.

III. ABBREVIATIONS:

MartMartius
Glu: Glutamic acid
Phe: Phenylalanine
Leu: Leucine
GC-MS: Gac Chromatography Mass spectroscopy
MCF-7: Michigan Cancer Foundation-7 (Human Breast Cancer Cell)
HeLa cellsHenrietta Lacks(Abnormally deviding human cells)
HepG2Hepatoblastoma cell line
SGOTSerum glutamic-oxaloacetic transaminase
SGPTSerum glutamic pyruvic transaminase
DNADeoxyribonucleic acid
LD50 Lethal dose of drug in 50% population
LC50 Exposure concentration of a toxic substance lethal to half of the test animals.

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