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PISTIA STRATIOTES L. (ARACEAE): PHYTOCHEMISTRY, USE IN MEDICINES, PHYTOREMEDIATION, BIOGAS AND MANAGEMENT OPTIONS

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Abstract

Pistia stratiotes L. commonly known as water lettuce belongs to Araceae. It has been used in various medicines for the treatment of eczema, leprosy, ulcers, piles, stomach disorder, throat and mouth inflammation, a few to mention. This review article is a compilation of the updated information regarding phytochemical, pharmacological, medicinal, bioremediation potential, allelopathy, utilization and management of water lettuce. In Pakistan it was first reported from Razmak, South Waziristan in 1972, but now it is widespread throughout the country. Information regarding the uses and effects of different extract (ethanolic and methanolic) of this plant is also documented. *Pistia stratiotes* possess different useful activities like, diuretic, antidiabetic, antidermatophytic, antifungal, and antimicrobial properties against harmful diseases. It has great potential for absorption of heavy metals (Fe, Zn, Cu, Cr, and Cd) without developing any toxicity or reduction in growth due to metal accumulation and has shown a wide range of tolerance to all the selected metals and therefore can be used for water purification and to combat water pollution in waste water bodies such as drainage ditches and channels carrying industrial effluents. This article provide bases and encourages further study on any of the above mentioned aspects of *P. stratiotes* for creation as well as confirmation of the information and also to reveal therapeutic effects, bioremediation and bioaccumulation potential with possible isolation of active bio-moieties and their mechanism of action.

Introduction

Pistia stratiotes, also known as 'Jal kumbhi', water cabbage, water lettuce, Nile cabbage, or shellflower is a free floating aquatic plant of streams, lakes and ponds. Due to its stoloniferous nature it is always found anchored to the hydrosoil when the water level recedes and in marshland conditions and loves alkaline/lime-rich water. *P. stratiotes* belongs to arum/ Araceae family (Quattrocchi & Umberto, 2000). As a floating weed it forms dense mats on surface of water bodies, disrupting aquatic flora and fauna underneath and thus adversely affects the water ecosystem and hinders water flow, fishing, swimming, boating, water sports and navigation (Attionu, 1976; Holm *et al*., 1977; Bruner, 1982; Sharma, 1984). It lowers available oxygen and pH of water and thus damages rice crop when enters into paddy fields, develop roots in the soil and competes with crop under shallow water conditions (Hussain *et al.*, 2000). It replaces the native hydrophytes in ponds and other water reservoirs (Marwat *et al*., 2010). The plant serves as a preferred host for mosquitoes, vectors of malaria, encephalomyelitis and rural filariasis. The Anopheles mosquito, which carries the parasite responsible for malaria, is frequently associated with *P. stratiotes* because the hydrophyte provides suitable shelter and breeding site (Holm *et al.*, 1977). Being a serious weed in more than 40 countries (Holm *et al*., 1979), it is used as feed for swine as well as buffalos (Mukhtar & Hafiz, 2001). Similarly a large number of medicinal and other uses are attributed to *P. stratiotes* which makes it a very special plant to be exploited (Kirtikar & Basu, 2001). Recently spread disease like dengue, causeb by mosquitoes may also rely on this plant but further studies are needed.

The recent upsurge in herbal medicines has made it possible to transform traditional medicine into a modern industry to deliver healthcare to the common man (Joseph & Justin, 2011). This revival of interest in plant derived drugs is mainly due to the current widespread belief that "green medicine" is safe, and clinically effective, better tolerated by patients, less expensive and globally competitive (Epko *et al*., 2011; Pradhan *et al*., 2009). Looking to *P. stratiotes* from medicinal point of view it is used as antiseptic, antitubercular and antidysentric. Its extract is used as an anodyne for eyewash and for relieving ear complaints. Its ash is applied to scalp for curing ringworm. Leaf extract is used in eczema, leprosy, ulcers, piles, and syphilis. Leaf extract boiled in coconut oil is applied to the skin in chronic dermatitis (Kirtikar & Basu, 2001). Its concoction is useful for relieving nervous disorders, fever and intestinal bacterial infections. *P. stratiotes* is useful in the treatment of stomach disorder, throat and mouth inflammation (Mukhtar & Tukur, 2000). It was reported that ethanol and hot water fractions of the plant exerts antimicrobial action on a few pathogenic bacteria while chloroform fraction of the same plant possess both antifungal and antibacterial activities on some pathogens (Mukhtar & Huda, 2003).

Water lettuce is capable to remove nutrients and heavy metals from the sewage sludge and drainage ditches. It is the most suitable plant for waste phytoremediation in tropical areas. Fonkou *et al*., (2002) reported that the physicochemical parameters reduce progressively from the influent to effluent ponds like turbidity, phosphates, total iron, sulfates and suspended solids. The improper sewage disposal is a big environmental concern which is impossible to solve with conventional methods as these methods are expensive and labour intensive. Waste disposal is a major concern in developing countries like Paksitan. The only solution is to devise a system based by using aquatic plants to treat wastewater, as suitable alternative which is cost-effective and safe to treat sewage (Reddy & Smith, 1987; Cooper

& Findlater, 1990). This paper highlights the importance of *P. stratiotes* as a medicinal plant, its utilization for the benefit of the society, and how to manage it where it has become a noxious weed.

The most ideal condition to avoid *P. stratiotes* will be to prevent the introduction of water lettuce; which requires a lot of awareness on the part of the state as well as public (Pheloung, 1995). However once the infestation occurs then any of the control method should be adopted which best suits the situation alone or in combination with each other as integrated weed management approach. Since it is a perennial weed of rice, therefore integration of crop rotation, puddling and use of rice herbicides can effectively control the weed (Marwat *et al*., 2010). Several researchers (Shehzad *et al.,* 2013; Usman *et al.,* 2013) have reported the importance of weeds and their potential disadvantages. The most common physical control method is raking or seining it (using a large fishing net) from the pond's surface. Raking can be done by using mechanical harvesters. The plant is then removed from waterways to the shore where it is cut up by chopping machines and disposed of by spraying across the water (Ramey, 2001). Chemical control methods that have been successful in treating *P. stratiotes* include the herbicide endothall, which can act quickly and kill all plant cells that it contacts. However, water lettuce has also been effectively and completely controlled in many countries by the leaf-feeding weevil, *Neohydronomus affinis* under laboratory conditions. In a field study in a drainage ditch with highly eutrophic conditions the weevil controlled the thick mats of the water lettuce completely to 0.5% in a single season. The plant is affected in all respects from control point of view (Moore, 2005). The paper explores medicinal, bioremediation potential with a touch of management strategies of water lettuce and provides a launching pad for further study in this regard.

Distribution

Water lettuce is widely distributed in Pakistan in reservoirs, ponds, marshy areas, lakes and stagnant water bodies (Marwat *et al*., 2010). Being an exotic plant; the exact way and time of its introduction to Pakistan is unknown, but according to Stewart (1972), it was first time reported from Razmak, South Waziristan, Pakistan but now it can be found countywide up to 2500 meter altitude. Fawad *et al*., 2013 reported that *P. stratiotes* L., was the most problematic and abundant weed in all habitats and water bodies of Swabi district of Khyber Pakhtunkhwa. On world level it is one of the most widely distributed hydrophytes in the tropics. It was first discovered from the Nile and presently it occurs in nearly all fresh bodies in tropical and subtropical regions. According to Holm *et al*., (1977) it has a cosmopolitan distribution and is considered indigenous in South and Central America, Africa and South-East Asia. It was introduced into Australia some 50 years ago. Gillet *et al*., (1988) are of the opinion that it is indigenous in the Northern Australia, where its natural enemies are regulating its population and has not been recorded at nuisance levels in this area, which creates the possibility that this area might be native for this plant.

The widespread distribution in most countries might be due its medicinal use or fodder for cattle and pigs (Sculthorpe, 1971). Its growth is limited by low temperatures (Small, 1933; Muenscher, 1967; Wiggins, 1980). However, scattered ephemeral populations have been reported from some colder climates (Dray & Center, 2002) where it acts as annual and rely on germination from seeds and on re-introductions; often discarded from aquarium in water bodies (Pieterse *et al*., 1981). *P. stratiotes* occurs in the Nile Delta in Egypt, but due to colder climate it does not attain the status of a major aquatic weed as compared to tropical conditions (Tackholm, 1974). Nile river studies indicated presence of herbivores in Southeast Asia (Habeck & Thompson 1997) and medicinal use in India and southern Asia (Stoddard, 1989; Tripathi *et al*., 2010). Documented introductions and its non-native status are confirmed for Southern Australia and New Zealand (Waterhouse, 1997) remote islands of the tropical Pacific (Fosberg *et al*. 1987), Slovenia (Sajna *et al*., 2007) and southern Idaho (Howard, 2010). Water lettuce's over growth make it invasive species (Holm *et al*., 1977). This weedy habit and bio geographic ambiguity have together made this plant a classic example of a cryptogenic species in many areas of the world (Rana & Ranade, 2009).

In Pakistan, *P. stratiotes* is wide spread and is found everywhere in almost all aquatic bodies. While in Khyber Pakhtunkhwa province, this weed is a major aquatic weed in all distracts and so far there is no use of this plant. It seems that there is a great potential to use this weed as medicine, fertilizer and for phytoremediation. However, detailed studies that address all the possible uses needs to be explored.

Botanical description: *Pistia stratiotes* L., is a free-floating, aquatic plant with sessile leaves forming a rosette. The leaves are pale-green, 10-20 cm long and 10 cm wide, spathulate to obovate with a rounded to truncate apex. Around 7-15 veins run parallel from the base. The lower surface is covered with whitish hairs (Cook *et al*., 1974; Aston, 1977; Holm *et al*., 1977; Sainty & Jacobs, 1981). Inflorescence is axillary, solitary, spathulated with a single pistillate flower at base, and 2-8 staminate flowers above. Flowers are unisexual, staminate with two stamens, pistillate with unilocular ovary having numerous ovules, a slender style and penicillate stigma, the fruit with many thin seeds (Acevedo-Rodriguez & Nicolson, 2005). Its seeds germinate on the hydro-soil and float to the surface within 5 days. Germination can also occur in the dark. *P. stratiotes* does not survive freezing temperatures. Germination does not occur below 20°C. It flowers in summer and give fruits at the end of hot season (Chadha, 1998). The seeds float on the surface for few days, transported by currents and water fowl, before they sink to the bottom (Holm *et al*., 1977). *P. stratiotes* varies largely owing to the influence of environmental factors.

Habitat: *Pistia stratiotes* is an aquatic plant, weed of stagnant water, can be more problematic in rice in the future (Marwat *et al*., 2010). It grows in a very wide variety of aquatic habitats. It requires a moist habitat, founds in lakes and rivers but prefers relatively stagnant

water. It can survive terrestrial condition by anchoring to the hydro-soil for a few weeks when the water level recedes. It is very sensitive to frost; the best range of temperature is 15-35°C (Rivers, 2002). It has a low salinity tolerance; salt concentrations of 1.66% are toxic to the plant (Haller *et al*., 1974).

Phytochemistry: *P. stratiotes* plant extracts consist of various alkaloids, glycosides, flavonoids and phytosterols. Leaf and stem extract consist of 92.9% H_2O, 1.4% protein, 0.3% fats, 2.6% carbohydrates, 0.9% crude fiber and 1.9% minerals (mostly potassium and phosphorous). Leaves are rich in vitamins A & C, stigma-sterol, stigma-steryl, stigma-sterate and palmitic acids are found in abundance. 2-di-cgl-cosy-flavones of vicenin and lucenin type, anthocyanin cyaniding-3-glucoside, luteolin-7-glucoside and mono-C-glcosyl flavones–vitexin and orientin have also been isolated from the plant (Khare, 2005). Stratioside II (a new C13 norterpene glucoside) is the major component of this plant. Leaves are rich in proteins, essential amino acids, stigmatane, sito-sterol acyl glycosides and minerals (Ghani, 2003). Vicenin an anticancer agent (Nagaprashantha *et al*., 2011) and cyanidin-3-glucoside (an anthocyanin) is present (Rastogi & Mehrotra, 1993). Aliotta and Monaco (1991) isolated sitosterol acylglycosides; phytosterols from the ethereal extract of *P. stratiotes*. The plant contains large amounts of di-c-glycosyl-flavones similar to vicenin and lucenin and their derivatives, traces of anthocyanin; cyanidin-3-glucoside and a luteolin-7-glycoside, mono-c-glycosylflavones, vitexin and orientin (Zennie & McClure, 1977). Using column chromatography resulted in isolation of stigmastanes as well as eight new compounds as Ergosta-7, 22-diene-3,5,6-triol, 7-hydroxyl-sitosterol, sitoindoside, soya-cerebroside, luteolin, chrysoeriol 4-*O*-D-glucopyranoside, sitosterol and daucoterol (Liu *et al*., 2008; Monaco, 1991). The flavonoid chemistry of *P. stratiotes* shows an evolutionary link between the aroids and the lemnaceae due to similar biochemical pathways to most flavonoids, which strengthens the concept that lemnaceae may have arisen from a *Pistia*-like ancestor (Zennie & McClure, 1997). *P. stratiotes* can be used as a model plant in biochemical study of oxalic acid formation and calcium regulation as related to calcium oxalate production in pure cultures (Tarlyn & Kotsman, 1998).

Utilization of *Pistia stratiotes*

Biogas production: *Pistia stratiotes* can be utilized as a substrate for biogas production in batch digestion. With inoculation, a high rate of biogas can be sustained for nearly 10 days with an average 58-68% methane production and significant concentrations of propionic, butyric, isobutyric, valeric, and isovaleric acids. These acids are present only in detectable concentrations during the first 4 days. The addition of inoculum improves the performance significantly (Abbasi & Nipaney, 1991). It can be exploited for bio-fuels through GM bacteria; consequently this will help in managing the weed, mitigating water pollution, relieving energy problems and protecting the aquatic ecosystem (Julias *et al*., 2012).

Role in water purification: *Pistia stratiotes* L. is a 'hyperaccumulator' by removing heavy metals, organic compounds and radio-nuclides from water (Sinha *et al*., 2006). It purifies the polluted aquatic system from detrimental metals. Application of plants for remediation of contaminated soil and aquatic system is increasing due to its low cost and lesser harmful effects than any other method (Ignjatovic & Marjanovic, 1985; Reddy & DeBusk, 1986; Prasad & Freitas, 2003). Lower size of the plant for removal of heavy metals is a credit for this plant as compared to water hyacinth (Quinones *et al*. 2006; Sinha *et al*. 2009; Mufarrege *et al*. 2010; Singh and Sinha 2011). It can be used for Zn extraction from industrial wastes as it has strong affinity to Zn absorption in an eco-friendly manner (Nurhayati *et al*., 2012). The same is true about mercury too (Skinner, 2007). The accumulation of heavy metals like Fe, Zn, Cu, Cr, and Cd does not cause any toxic effect on the plant which qualifies the plant to be used for the phyto-remediation of waste water for heavy metals on large-scale (Mishra *et al*., 2008). It has been considered a promising plant for the remediation of contaminated waters (Maine *et al*., 2001).

Gujarati *et al*., (2005) reported that the fate of antibiotics used in US in feed for livestock is their presence in our food. They enter to waste water streams from feedlots and farmyard manure. Microbes in the water bodies are predisposed to develop resistance in these antibiotics; producing resistant human pathogens causing severe diseases. Phyto-remediation of these antibiotics is a useful tool to resolve the issue. Water lettuce gave high antibiotic modification rates through root exudates tetracyclines and oxy-tetracyclines; the two frequently used antibiotics in veterinary feed and medicines. *P. stratiotes* is best candidate for in situ bioremediation of drug contaminated water body as it is more sensitive than the other aquatic plants tested. Thus it is recommended for quinolone bioremediation but less effective for sulfonamide (Forni *et al*., 2006).

Biological and pharmacological activities: *In vitro* free radicals cause tissue injury and consequently cause many diseases like arthritis, hemorrhage, arteriosclerotic vascular disease, diabetes, hepatitis etc. *Pistia stratiotes* leaves extract is capable to reduce superoxides and nitric oxide radicals and to lower free radical induced cell injury. The ethanolic extract of this plant leaves inhibits the enzyme xanthine oxidase and hence uric acid formation, the xanthine oxidase inhibitor is used in the treatment of gout (Jha *et al*., 2010). The antipyretic nature of the extract can be utilized for treating fever (Kumar *et al*., 2011). The leaves are used as disinfectant and for the treatment of tuberculosis, dysentery, eczema, leprosy, ulcer, piles, syphilis and parasitic worms (Anon., 1999; Kumar *et al*., 2010). The ash of water lettuce is used for curing tinea. Egami *et al*., (1998) reported the antibacterial activity in the plant. *P. stratiotes* works as antioxidant (Thuong *et al*., 2006), bronchodilator (Achola *et al*., 1997), antitumor (Fatope *et al*., 1993), antifungal (Premkumar & Shyamsundar, 2005), diuretic (Pallavi *et al*., 2011), antiprotease (Jedinak *et al*., 2010), emollient (Tripathi *et al*., 2010), antidiabetic (Joy *et al*., 2001) and antimicrobial (Abu Ziada *et al*., 2008). Kumar *et al*.,

(2010) studied the ethanolic extract of *Pistia* against human parasitic worms in comparison with the standard medicines like piperazine citrate and albendazole and found that the extract was as useful as the standard drugs.

Anti-inflammatory activity: Anti-inflammatory herbal medicine with low side effects is much valued (Tripathy *et al*., 2010). Water lettuce is traditionally used for curing opthalmia and iritis in Ghana, due to its analgesic anti-inflammatory effect (Abbiw, 1990; Arber, 2002; Tripathi *et al*., 2010; Kumar, *et al.,* 2011). Its water and ethanolic extracts given in acute inflammation relieve hyperalgesia by inhibiting the chemicals (histamine, serotonin, prostaglandin, and bradykinin) that stimulates and sensitizes the nociceptors (Koffuor *et al*., 2012). The phytochemical screening revealed presence of some flavonoids and sterols, which might be the source of the anti-inflammatory activity of this plant (Pelzer *et al*., 1998; Funakoshi *et al.,* 2011). The sterols have structural resemblance to steroids and are known to soothe irritation (Mencarelli *et al*., 2009).

Diuretic activity: Pallavi *et al*., (2011) reported antidiabetic and diuretic activities in the leaf extracts of water lettuce. They found that oral administration of the extracts produced significant diuretic action which might be its ability to block sugar absorption. The diuretic activity of ethanol leaf extract of *Pistia stratiotes* was proved very effective in the laboratory trials on albino rats. The extract increased the bulk of urine and regulated the balance of electrolytes depending on dose and time interval between doses. The results revealed that ethanol leaf extract of this plant has significant diuretic activity, and supports the traditional practice of using water lettuce as diuretic (Sahu *et al*., 2009).

Antifungal activity: Dermatophytes are fungi that affect the keratinous tissue (hair and nails) causing superficial infections (Conant *et al*., 1991). Natarajan *et al*., (2003) found that *P. stratiotes* methanolic extract was most effective against dermatophytes. The antifungal activity of water lettuce justify its use for curing different diseases with fungal or fungal-like symptoms, like ringworm infection of the scalp, syphilitic eruptions, skin infections, boils, and wounds, and highlight the worth of indigenous knowledge of ethno-botany in choosing water lettuce to discover new medicines. Further research is required to investigate the biochemicals responsible for the antifungal activity of this plant (Kirtikar and Basu, 2000; Premkumar & Shyamsundar, 2005).

Anti microbial activity: In agriculture and medical sectors drug resistance is on the hike, compelling us to think of a new antibiotic based herbs instead of synthetic origin to combat pathogen (Pai *et al*., 2004; Shah, 2005; Ibrahim *et al*., 2011; Obeidat *et al*., 2012). This slogan has elevated the demand for the green products such as *Pistia stratiotes*; a rich source for new bioactive compounds. The extract of this plant has showed antibacterial (Abu Ziada *et al*., 2008; Fareed *et al*., 2008; Sridevi *et al.*, 2010), antifungal (Bhosale *et al*., 1999; Haroon, 2006), antiviral (Verma *et al*., 2008; Shin *et al*., 2010; Sohail *et al*., 2011) and antialgal activities (Li & Hu, 2005; Yi *et al*., 2012). Soetan *et al*., (2006) and Yisa (2009) reported that flavonoids and phenolic derivatives of water lettuce affected the function of bacterial cell membrane as a result inhibited their growth (Trombetta *et al*., 2005; Hendrich, 2006). In addition, the extracts possess some antimicrobial agents whose nature and number is not clear, however their worth should not be undermined. Further study should be done to purify and identify them (Daboor & Amany 2012).

Wound healing potential: Plants have compounds that help the wound to heal quickly (Kalyon *et al*., 2009). *Pistia stratiotes* contains large amount of compounds that have antioxidant activity (Zennie & McClure, 1977). For example sterols from this plant are reported to be responsible for wound healing property of the plant (Ayyad, 2002). Tremendous research has been conducted for the discovery of new antioxidants from herbs to prevent damage from free radical (Chen *et al*., 2011; Huang *et al*., 2011). In this regard topical application of water lettuce plant material at the wound increased wound healing significantly. The healing potential might be due to its ability to trigger angiogenesis and mitogenesis at the site (Gupta *et al*., 2009). The antioxidant property of any substance is believed to promote wound healing resulting in skin regeneration. The antioxidant activity of water lettuce extract is well known, which prevents oxidative damage and encourages the process of healing. The wound-healing property of water lettuce is attributed to certain compounds present in the plant which work alone or in combination with other compounds in the healing process. Further study is needed for isolation, characterization and identification of these bio-compounds (Jha *et al*., 2012).

Allelopathic effects on terrestrial plants: Annually *P. stratiotes* produces 10-30 tons dry biomass ha^{-1} (Leng, 1999) while according to Gumbricht (1993) 60-110 tons ha^{-1} $year^{-1}$, respectively. Walstad (1999) stated that such a high biomass production indicates an elevated potential of allelopathy in the plant; releasing allelochemicals in its vicinity that prevent other plant to compete with it. Its phytotoxic effect is dependent on: amount and composition residues, the environment and management practices (An *et al*., 2000). To date, six allelochemicals have been isolated from leaf ethyl-ether extract that suppressed the growth of some phytoplankton and multicellular algae (Aliotta *et al*., 1991). The allelopathic potential of water lettuce is a best source for weed management. Currently it is under screening process (Xuan *et al*., 2005). Screening provides important basic information on inhibitory effects and their potential for weed control (Macias *et al*., 2007). Golisz *et al*., (2008) reported that some alellochemicals caused root cell death indirectly by production of reactive oxygen species that worked as signaling molecules that changed hormonal balance during seed germination (Bogatek & Gniazdowska, 2007). Germination of lettuce in aqueous extracts of corn residues, caused necrotic root tips and shorter roots due to damage of meristematic tissue (Chou & Patrick, 1976). Eucalyptol also inhibits the roots growth of lettuce seedlings (Romagni *et al*., 2000a). Thus shoot/ root inhibitors can be utilized in weed management (Monaco *et*

al., 2002). Bich & Hisashi (2012) reported that *Lemna* and *Pistia*'s water and methanolic extracts affected the growth of some dicot and monocot plants. In allelochamicals are specific in action which might suppress one species leaving the other unharmed (Xuan *et al*., 2005).

Miscellaneous uses: In many Asian and African countries and Brazil *P. stratiotes* leaf extract is used for topical application for various skin diseases and taken orally as laxative and diuretic. It is used for productive cough and asthma along with rose water and sugar. They are also used for treating piles and gonorrhoea. Water lettuce decoction is taken to relieve indigestion, urgency and frequent urination and in baths for reducing hydropsy. The leaves work as appetizers but cause loose motion if overdosed. Water lettuce provides a shelter and food to various types of fishes so their presence is valued for fishermen of Java. Indians and Chinese cook the plant and fed to pigs and ducks, while it is given fresh to rabbits. It can be used as food during food crisis, although it is not palatable. It can be used as a pot herb with sharp taste due to CaC_2O_4 which causes kidney stone. Due to high potash value it can be used as green manure for potash deficient soils. The high potash content enables it to be used with soap to increase its efficiency. It is grown in aquariums and ponds for aesthetic purposes in some tropical countries but it is thrown in the water bodies in winter where it becomes a noxious weed (Schmelzer *et al*., 2001).

Impacts on the aquatic ecosystem

An invasive weed: Water lettuce found in the irrigation channels transpires a lot of water and interferes with paddy crop (Holm *et al*., 1977; Waterhouse, 1993). *P. stratiotes* is an invasive weed in tropical and sub-tropical conditions, mat forming and rapidly covering the whole water body, preventing sunlight, affecting water use efficiency and intended use of water badly. Under the dense mats available O_2 decreases, negatively affecting biological oxygen demand (BOD) and aquatic plant and animals consequently lower biodiversity in invaded water bodies (Langeland & Burks, 2008). Moreover, it blocks water flow, hinder electricity generation from dams and harbor dangerous pests (Mbati & Neuenschwander, 2005; Gangstad & Cardarelli, 1990). The excessive growth of water lettuce is due to nutrient enrichment, which must be discouraged to combat this problem (Vaithiyanathan & Richardson 1999). The dense mates of water lettuce pose a threat to life of human and livestock by getting entangled (Anon., 2013).

Management of *Pistia stratiotes*

Physical/mechanical control: Water lettuce can be managed manually by hand pulling on small scale. In case of deep water it can be removed by using nets and certain barriers. However, IN Pakistan this weed is a major problem in shallow water bodies especially drainage systems and small ponds. So far there is no use of this weed. The weeds complete their life cycle and thus add nutrients to the water bodies which further accelerate the problem due to availability of nutrients. Mechanically the weed mat can be cut and the pieces pulled out to the bank of water body manually or by using machines like tractor or excavator or boats depending on size of water body. The use of heavy machines is necessary if it grows mixed with rooted aquatic weeds (Wade, 1990). Combine harvester capable of cutting, collecting and bringing the biomass to the shore can also be used in case of heavy infestation and on large scale. But this will not ensure the complete elimination of the plant and re-establishment may occur, necessitating a long-term control program. Control measures to be used, should be cost effective and economical taking into consideration the water body, intended use of water body and its impact on the fauna and flora of that area.

Chemical control: Water lettuce can effectively be controlled by sulfonylurea herbicides like chlorsulfuron (Madin, 1984) and contact herbicides like paraquat and diquat (Thayer & Haller, 1985) and non-selective systemic herbicide like glyphosate (Thayer & Haller, 1985; Van *et al*., 1986), a mixture of diquat and triclopyr (Langeland & Smith, 1993), terbutryn (Vermeulen *et al*., 1996), 2,4-D (Langeland & Smith, 1993) and endothall (Rivers, 2002). However chemical control endangers the environment and should be avoided for a better alternative approach if possible. As it will suspend the use of water for a considerable period and disturb the balance of the aquatic ecosystem by negatively affecting other plants and animal lives. It may create health hazards for the local people and birds specially in developing areas. In indispensable situation special formulation with low mammalian toxicity should be used as AF101 (Parsons & Cuthbertson, 1992).

Biological control: *Neohydronomus affinis* is an excellent biological control agent for water lettuce (O'Brien & Wibmer, 1989). The weevil (*N. affinis*) is native to S. America. DeLoach *et al*., (1976) recommended this for various parts of the world (Harley *et al*., 1990; Anon., 1995) where it proved worthy and provided an adequate level of control. Another insect; the water lettuce moth (*Spodoptera pectinicornis*) was screened out and recommended from Thailand for biological control of *Pistia* in United States (Habeck & Thompson, 1994). In an integrated attempt three different species of weevils were employed (*Argentinorhynchus bruchi, A. breyeri* & *A. squamosus*) which successfully managed water lettuce spread under laboratory conditions (Anon., 2001). Similarly, fungi *Ramularia* spp. and *Sclerotinia sclerotiorum* have also shown potential for managing water lettuce (Fernandes & Barreto, 2005; Waipara *et al*., 2006). Up till now 21 biological agents have been reported that control *P. stratiotes;* 5 from Africa, 11 from Asian countries and 9 from Florida (Dray & Center, 2002). The Larvea of *A. drumalis* feed on the roots of water lettuce.

Conclusion

Pistia stratiotes is a valuable multiuse plant as well as an invasive aquatic weed in Pakistan. It is one of the most widely distributed hydrophytes with cosmopolitan distribution in tropical and sub-tropical regions. Being a hyper-accumulator it is the cheapest tool for the phyto-remediation of polluted water bodies in removing heavy metals and to denature the antibiotics released into water. *P. stratiotes* contain alkaloids, glycosides, flavonoids, and steroids, vitamin A, B and C, proteins, essential amino acids, and minerals. Its leaves are used in traditional medicine for treatment of ringworm, syphilis, skin infections, boils, wounds, fever, tuberculosis and dysentery in many countries of the world. *P. stratiotes* posses various biological activities like antibacterial, antioxidant, bronchodilatory, antitumor, antidermatophytic, antifungal, diuretic, antiprotease, antidiabetic and antimicrobial. It is allelopathic causing harmful effects on other plant through allelochemicals. Favorable condition and nutrient enrichment in the water bodies makes it an invasive plant and necessitates its control through physical, chemical, or biological methods. Further study on the isolation and identification of the various bioactive compounds, its role in bio-remediation and different methods of its control is strongly recommended. As this weed contain nutrients therefore this weed can be explored to possible use as fertilizer. Collection, processing and application at large scale might be difficult but kitchen gardeners can be motivated to collect this plant and use as fertilizers. However, the heavy metal accommocation and the related ill effects need to be investigated.

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