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ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.7, No.4, pp 1849-1861, 2014-2015

Geographical distribution and physiology of water hyacinth (*Eichhornia crassipses*) – the invasive hydrophyte and a biomass for producing xylitol

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Abstract: At present Water hyacinth (*Eichhornia crassipses*) have been ranked as one of the world's worst invasive weeds causing problems to millions of users of water resources. It is known as "Blue Devil" or "Bengal terror" in India, "Florida devil" in South Africa, "German weed" in Bangladesh and "Water terror" by South Western Nigeria[1] with its disruptive impacts on aquatic ecosystem, agriculture, fisheries, production from electricity from hydral power plants, transportation, living conditions and social structures. In last few decades, a special interest has been drawn on this weed for utilising it as an effective water hyacinth biomass (WHB) for production of biofuel, fertilizers, paper etc. It is also utilised in bioremediation and waste water treatment. In this paper the wide geographical distribution of water hyacinth along with the anatomical study of different plant parts and the methodologies adopted for the production of Xylitol has been included. Xylitol is a 5 C sugar poly-alcohol obtained from hemicelluloses of WHB by hydrolysis and fermentation, a sugar substitute for diabetic patients, harmless food , non toxic with many other beneficial role to mankind.
Keywords : Water hyacinth, Geographical distribution, Xylitol production, Anatomical study of water hyacinth.

Introduction:

The Water resources are exclusively important for the environment, industry, domestic and agricultural purposes. In last few decades, due to fast technological and industrial development with rapid urbanisation several problems arrised related to water which is an important resource for food and energy. Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is a prolific free floating aquatic macrohpyte which has proven to be a significant economic and ecological burden to many sub tropical and tropical regions of the world[2]. Water hyacinth has been listed as one of the most productive plant on earth which has invaded freshwater system in over 50 countries on five continents, especially throughout southeast Asia, the southeastern United States, Central and western Africa and Central America[3,4,5,6]. It is efficient in utilizing aquatic nutrients and solar energy for profuse biomass production, causing extensive environmental, social and economic problems. It is found in lakes and estuaries, wetlands, marshes, ponds, dambos, slow flowing rivers, streams and waterways in lower latitudes where growth is stimulated by the inflow of nutrient rich water from urban and agricultural run off, deforestation, products of industrial waste and insufficient wastewater treatment[7, 8]. According to recent climate change models its distribution may expand into higher latitudes as temperature rise posing problems to formerly water hyacinth free areas[9].

Eichhornia crassipes (Mart.) commonly known as water hyacinth is a free floating perennial aquatic monocotyledonous plant belonging to family Pontederiaceae. During the past century, it has spread from its native tropical & sub tropical South America to worlds most serious aquatic weed[10,11]. It has become naturalized in many warm areas of the world: Central America, North America (California & Southern States), Africa, Asia, Australia, New Zealand and India. This plant is a native of Amazon basin, Brazil which made its appearance at 1884-85, Worlds Industrial and cotton Centennial Exposition. Within 20 yrs, water hyacinth made its way into the waterways of all the Gulf coast states. It grew at a rate of 2 x 10^5 hectares per year, spreading at an alarming rate. It was brought to Europe by 1879, where the plant was killed by post and does not survive due to prolonged winter. Then it was introduced to Europe around 1880, when it became a serious pest. The Nile River is currently infested with large population of this weed, rapidly spreading throughout the African continent. Then it made its way to Australia and southern Asia by 1990. Water hyacinth being the world's worst weed is also listed as one of the most productive plant on earth on the other hand. Along with its negative economic impacts worldwide which include clogging of irrigation channels, choking off navigational routes, loss of fishing area, depletion of oxygen, nutrients from water bodies, it has wide importance in waste water treatment, excellent source of biomass due to high productivity, used as fertilizers, ethanol, Natural gas, Methane etc can be produced. Also some value added products as Xylitol etc can be produced as the biomass is rich in cellulose and hemicelluloses content containing hexose and pentose sugars. The objective of this paper is to study the geographical distribution of Eichornia crassipses, its impact on mankind and bioconversion process of Xylitol.

Geographical Distribution

Water hyacinth is found across the tropical and subtropical regions, originated from the Anazon Basin, but its entry into Africa, Asia, Australia and North America was facilited by human activities[12].Along with the United States, 56 other countries has reported it as a noxious weed[11].The geographical distribution also include Indo – China and Japan[13]. Within the U.S , *E. crassipses* occurs throughout the southeast, north to Virginia and West to Texas as well as in California & Hawaii. Seasonal escapes from cultivation are reported from Newyork, Kentucky, Tennessce and Missouri, but population apparently do not survive through winter[14]. In California, USA, this weed has caused severe ecological impacts in the Scramento- san Jaquin River Delta[15].In Mexico, more than 40,000 hactares of reservoirs, lakes, canals and drains are infested with water hyacinth[16]. In Europe, water hyacinth is established locally in the Azores (France) and in Corsica (Italy) and casual records are known from Belgium, the Czech Republic, Hungary, the Netherlands and Romania (EEA 2012). In particular it is a threat in Spain & Portugal[17]. In West Africa it was first reported in Cameroon between 1997 and 2000 and since then the country's wetlands have become "home" for the weed[18].In Nigeria almost all river bodies have been dominated by water hyacinth[19].The water hyacinth problem is especially severe on the river Niger in Mali where human activities and livelihoods are closely linked to the water systems. It occurs throughout the Nile Delta in Egypt and is believed to be spreading southwards, due to the construction of the Aswan Dam which has slowed down the river flow, enabling the weed to invade[12]. Infestation of water hyacinth in Ethiopia has also been manifested on a large scale in many water bodies of the Gambella area, Lake Ellen in the Rift Valley and Lake Tana[20]. Fig 1. represents the geographical distribution of water hyacinth around the world.

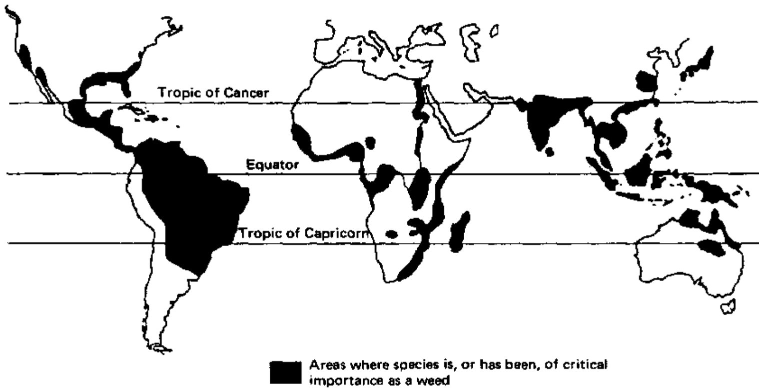


Fig 1 : Geographic Distribution of Water Hyacinth weed throughout the world.

In Asia water hyacinth is widespread on freshwater wetlands of the Mekong Delta, especial in Standing water (MWBP/RSCP, 2006). It has been detected in the Sunderbans mangrove forest of Bangladesh[21] and has caused heavy situation in the wetlands of the Kaziranga National Park, India. Deepor beel a freshwater lake formed by Brahmaputra river is heavily infested with this weed[22]. The lake is considered one of the large and important riverine wetlands in the Brahmaputra valley of lower Assam, India. It has also caused many social, economic & environmental problems in Southern China[23].

Origin

In 1823, the German naturalist C. von Martius discovered the species, while carrying out floral surveys in Brazil. He named it Pontederia crassipes. Solms included it in the *Eichhornia* genus, 60 years later, as had previously been described by Kuntz in 1829. However, a collector by the name of von Humbolt had already collected specimens from Colombia in 1801, together with the species azurea[24].The reason for the world-wide distribution of this weed varies, but generally it has coincided with the plant's ornamental properties or as feed[25].

Identification

Described to have dark, thick leaves that flattens out to make a mat on top of the water. It is a floating leaf or free-floating macrophyte with its reproductive organs on top as a purple flower on top of its mat. The roots of water hyacinth's are thick and dense that is used by many macro and micro invertebrates and small or juvenile fish. The plant creates colonies and is likely that one will never see *E. crassipes* as a single standing plant. The taxonomy, morphology, anatomy and ecology of water hyacinth – Eichhornia crassipes are described in Table 1.

Table 1: Taxonomy of Water hyacinth

Kingdom	Plantae, Plants
Subkingdom	Tracheobionta Vascular plants
Superdivision	Spermatophyta Seed plants
Division	Magnoliophyta Flowering plants
Class	Liliopsida Monocotyledons
Subclass	Commelinidae [Liliidae]
Superorder	Commelinanae
Order	Pontederiales [Philydrales]
Family	Pontederiaceae
Genus	*Eichhornia*
Species	*Eichhornia crassipes* (water hyacinth)

Morphology

Water hyacinth is a perennial, aquatic plant, free-floating or anchored in shallow water. Usually 100 – 200 mm high, it can extend to 1 meter when growing in dense mats. Roots of floating plants are long and feathery. Leaves of water hyacinth are shiny dark green in colour, in rosettes with distinctive erect swollen bladder-like petioles. Flowers are pale violet or blue, in flowered spikes with each flower measuring about 50mm in diameter. The upper petal has a prominent dark blue, yellow-centered patch. Fruit consists of capsules with very fine seed[26].The root structure of the plant gives it a feathery appearance, due to it being adventitious and fibrous. As much as 50% of a single plant's biomass could be made up of the root structure[24]. The plant is shown in its flowering stage inside the CSIR- CMERI campus, Durgapur in Fig. 2.

Fig 2: Water hyacinth plant with flowers (Growing inside CSIR-CMERI campus (Latitude 23.5500° N, Longitude 87.3200° E)

Ecology

Invasive species are widely accepted as one of the leading causes of biodiversity loss and can have significant effects on resource availability and can suppress or enhance the relative abundance of native species, without necessarily being the driving force behind community change[27].A dense cover drastically reduces and may prevent light penetration of water. Without light, phytoplankton and submerged plants can not photosynthesize. Oxygen levels decrease and carbon dioxide increases, with catastrophic effects on the aquatic fauna[28]. Populations of fish can be reduced or eliminated, as well as other animals[29, 30]. Few invaded ecosystems are free from habitat loss and disturbance, leading to uncertainty as to whether dominant invasive species are driving community change or are passengers along for the environmental ride[31]. Water hyacinth has a direct impact on aquatic systems water flow by slowing it by 40 to 95% in irrigation channels[24, 32, 33], which may cause severe flooding. This could have a detrimental effect on the ecology of the system. In addition it is suggested that mats of water hyacinth lower temperatures, pH, bicarbonate alkalinity and dissolved oxygen content and increase the free carbon dioxide content, and nutrient levels[34,35,36,37]. Water hyacinth occurs in both highly acidic and alkaline waters but more luxuriant growth is observed in near neutral water bodies. The water may be clean and poor in major nutrients as in most rivers and reservoirs, or may be highly polluted with large amounts of nutrients and organic matter as in sewerage lagoons[24] and many aquatic systems in South Africa. One hectare of water hyacinth plants under optimum conditions could absorb the average daily nitrogen and phosphorus waste production of over 800 people[38]. Exotic species (water hyacinth) that invade systems represent a threat to that ecosystem and could directly modify an ecosystem, causing a cascading effect for resident biota e.g. space[39].

Habitat

Water hyacinth can be located worldwide in a variety of different habitats. These include habitats varying from shallow ponds, possibly temporary, to large lakes and even fairly fast flowing rivers[24]. Where the plant is situated in shallow water bodies it does not have to contend with excessive wave action and varying depths of water. The velocity of water also plays a significant role in the plant's habitat. Climatic conditions vary within a system and will have an effect on the ecology of the plant itself. Water hyacinth can be located in both natural water and artificially made aquatic systems. However, it does not occur in aquatic systems with an average salinity greater than 15% of sea water[13]. The plant grows prolifically in nutrient enriched waters and new plant populations form rooted parent plants. Wind and current assists to distribute them. Excessively large mats can be formed. The root system, as well as the above water structures of the plant, forms a habitat for organisms. However, large mats of water hyacinth are capable of negatively affecting the original habitat.

Spread and colonisation

Water hyacinth infestations increase most rapidly by the production of new daughter plants. During high water flows & flooding, infestations can break up and be moved to new locations. Most spread can be attributed to human activity such as the deliberate planting of water hyacinth in ornamental ponds or dams. Unwanted aquarium plants that are discarded into waterways are a major form of spread. Water hyacinth can also be spread by contaminated boating equipment. Seeds are the main source of new infestation which are carried in water, mud and birds. The success of this invasive alien species is largely due to its reproductive output. Water hyacinth can flower throughout the year and releases more than 3000 seeds per year[24] (EEA 2012). The seeds are long lived, up to 20 years. While seeds may not be viable at all sites, water hyacinth commonly colonises new areas through vegetative reproduction and propagation of horizontally growing stolons. In the early stages of infestation, the weed takes foothold on the shoreline in the areas where native aquatic plants thrive[40]. However it is not restricted to shallow water, unlike many submerged and mergent macrophytes, because its roots are free floating near the surface[7]. At present water hyacinth is widely distributed to over 80 countries around the world over 100 yrs.

Life Cycle

The life cycle of the *E. crassipes* is typical to most plants of the world. The water hyacinth germinates in the spring. The seed will drop either on the mat of the water hyacinth or into the body of water in which it will not take long for the plant to take root and grow. The plant will grow and create colonies through the year until winter in which, depending on the climate, will cease growth or die. Then, after the climate has warmed, the Water hyacinth will rebound and continue growing until spring in which the germination process begins again[13].

Reproduction

Water hyacinth is capable of sexual and asexual reproduction and both modes are important to the species' success as a pernicious aquatic invader. In mild climates, plants can flower year-round, and from early spring to late fall elsewhere. They can produce an abundance of seeds[41]. A study by Barrett (1980b) confirmed that tropical *E. crassipes* populations produced twice as many seeds as did temperate populations and attributed the difference to higher rates of pollinating insect visitation in the tropics. Seed germination tends to occur when water levels are down and the seedlings can grow in saturated soils. Vegetative reproduction occurs via the breaking off of rosettes of clonal individuals. The stolons (horizontal shoots capable of forming new shoots and adventitious roots from nodes) are easily broken by wind or wave action and floating clonal plants and mats are readily transported via wind or water movement[41,42].

Embryology

E. crassipes produces a thin walled, capsule-like fruit that is protected within structures that form from the perianth, the outer whorls of the flowers. Each capsule can hold as many as four hundred-fifty 4-mm long x 1-mm thick seeds[24]. Germination typically occurs in wet soil.

Effects of Water Hyacinth

Destruction of biodiversity

Water hyacinth is challenging the ecological stability of freshwater water bodies[15, 40], out-competing all other species growing in the vicinity, posing a threat to aquatic biodiversity[22]. Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries[7,40].

Oxygen depletion and reduced water quality

Large water hyacinth mats prevent the transfer of oxygen from the air to the water surface, or decrease oxygen production by other plants and algae[7]. When the plant dies and sinks to the bottom the decomposing biomass depletes oxygen content in the water body (EEA 2012). Dissolved oxygen levels can reach dangerously low concentrations for fish that are sensitive to such changes. Furthermore, low dissolved oxygen conditions catalyse the release of phosphorus from the sediment which in turn accelerates eutrophication and can lead to a subsequent increase in water hyacinth or algal blooms[42]. Death and decay of water hyacinth vegetation in large masses deteriorates water quality and the quantity of potable water, and increases treatment costs for drinking water[8,22,43].

Breeding ground for pests and vectors

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria[44]. Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed[45,46]. Snails serving as vector for the parasite of Schistosomiasis (also known as Bilharzia) reside in the tangled weed mat[19]. Water hyacinth has also been implicated in harbouring the causative agent for cholera. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the Province[47]. At the local level increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed which provides cover to the reptiles and poisonous snakes[8, 22].

Blockage of waterways hampering agriculture, fisheries, recreation and hydropower

Water hyacinth often clogs waterways due to its rapid growth and propagation rate. The dense mats disrupt socioeconomic and subsistence activities (ship and boat navigation, restricted access to water for recreation, fisheries, and tourism) if waterways are blocked or water pipes clogged[8, 22]. The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species[7]. In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing[48]. In the Wouri River Basin in Cameroon the livelihood of close to 900,000 inhabitants has been distorted; the entire

Abo and Moundja Moussadi creeks have been rendered impassable by the weed leading to a complete halt in all the socioeconomic activities with consequent rural exodus[49]. The weed has made navigation and fishing an almost impossible task in Nigeria[8].

While navigation in the Brahmaputra River in India has been affected by the weed, it has also blocked irrigation channels and obstructed the flow of water to crop fields. For example, in West Bengal, it causes an annual loss of paddy[22] by directly suppressing the crop, inhibiting rice germination and interfering with harvesting (EEA 2012). The dense growth entangles with boat propellers, hampering fishing[22]. Water hyacinth slows water flow by 40 to 95% in irrigation channels[50] which may cause severe flooding. The communities of Bwene and Bonjo in the Wouri River Basin in Cameroon regularly suffer from floods during the rainy season due to blockage of waterways around the villages by the weed[49]. It is estimated that the flow of water in the Nile could be reduced by up to one tenth due to increased losses from evapotranspiration by water hyacinth in Lake Victoria[8]. Water loss by the same process and blocking of turbines on Kafue Gorge in Zambia translates into lost water for power generation and eventually into lost revenue of about US$15 million every year for the power company (ZEO 2008). Many large hydropower schemes are also suffering with the effects of water hyacinth[51]. For example, cleaning intake screens at the Owen Falls hydroelectric power plant at Jinja in Uganda were calculated to be US$1 million per annum[52].

Cell wall composition of Water hyacinth

Plant biomass/Lignocellulosic feedstock is composed primarily of cellulose, hemicelluloses and lignin and smaller amounts of pectin, protein, extractives and ash. Distribution of cellulose, hemicelluloses and lignin as well as the content of the different sugars of the hemicelluloses varies significantly between different plants. Cellulosic materials are renewable natural biological resources. Lignocellulosic structure is complex. Carbon is locked in lignocellulosic structure in the form different types of sugars. The major carbon flow from fixed carbon sink to atmospheric CO_2 is cellulose biodegradation. It has been reported that the biomass of water hyacinth has about 48% hemicellulose, 18% cellulose 13.5% lignin[53]. Though there is a significant amount of variability in composition reported by different labs, in general the biomass is considered to be rich in hemicellulose and with very less lignin content. Table 2 shows the cell wall composition of water hyacinth growing inside CSIR-CMERI campus used in this study:

Table 2 : Cell Wall composition of water hyacinth

Plant Material	Leaf of WHB	Stem of WHB	Root of WHB	Uniform mix of Leaf and Stem
Cellulose %	30	36	9	33
Hemicellulose %	23	27	20	38
Lignin %	18	21	29	17

Experimental

Anatomical Study of Water hyacinth

The fresh plant parts i.e. rhizomes, roots, leaves and petioles were collected. Manual sectioning was done to study the plant material in cross sections and transverse sections. Epidermal peels scraped from adaxial and abaxial surfaces of leaves were obtained and studied. After sectioning, the material was stained in Safranine and Fast Green stains, and then mounted in a drop of glycerine jelly on glass slides. A cover slip was placed over them and observations were made. Microscope with 10× ocular and 10×, 40×, 100× objectives was used for all observations.

Microorganism

Candida shehatae and *Pichia stipitis* may be chosen as microorganisms for fermentation.

Preparation of water hyacinth

Fresh water hyacinth leaves with long stem is used for this experiment. Fresh plants are collected from CMERI, Durgapur Campus. It is washed thoroughly for several times with tap water to remove dirt, chopped into small pieces (~ 2- 2.5 cm), and made paste. Simultaneously some plants collected were chopped into small pieces, dried in hot air oven at 60-80° C for 5-6 hr, finally grounded to make fine powder which were again sieved to particle size (~ 100µm, 200 µm, 300 µm) The dried material is stored at room temperature for further use.

Pretreatment

The following process can be used for treatment of water hyacinth :

Steam Explosion

In this process, chopped water hyacinth needs to be treated with high pressure saturated steam and then the pressure has to be swiftly reduced, making the materials undergo an explosive decompression. Steam explosion has to be initiated at a temperature of 160 – 260 C at a pressure of 0.69–4.83 MPa for several minutes before the material gets exposed to atmospheric pressure. The process causes hemicelluloses degradation and lignin transportation at high temperature, thus increasing the potential of hemicelluloses hydrolysis.

Acid Hydrolysis

Water hyacinth needs to be hydrolysed using different concentration of Sulphuric acid (1%, 3%, 5%) to produce xylose, arabinose, glucose and acetic acid by cleavage of the β-1-4 linkages of glucose or xylosee monomers acetyl group. The fresh paste made was treated with the respective acid concentration with a soaking period (ST) for 1-4 hr along with an agitation of 130, 160, 190 rpm and finally boiled for certain period of time (5-30 mins). The primary advantage of this process is high sugar recovery efficiency.

Biological pretreatment

Biological pretreatment involves use of whole microorganism or enzymes in pretreatment of water hyacinth. Both fungi or bacteria may be used, which will improve the digestibility[54]. White, Brown, Soft rot fungi are generally used to degrade lignin and hemicelluloses in water hyacinth whereby brown rots mainly attack cellulose. White rot fungi are the most effective basidiomycetes for biological pretreatment of lignocelluloses material. Several xylanolytic, cellulolytic and lignolytic enzymes are secreted from several fungi which can degrade and involve in hydrolysis of sugar.

Schematic diagram of Production of Xylitol

The bioconversion of water hyacinth to value added product of xylitol can be best described by the following flow diagram and the biochemistry as shown in Fig 3 and Fig 4.

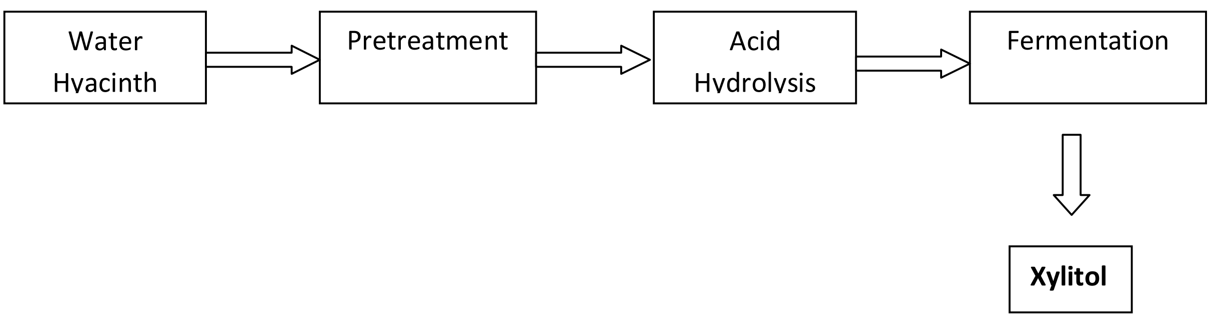


Fig.3 General Description of the process

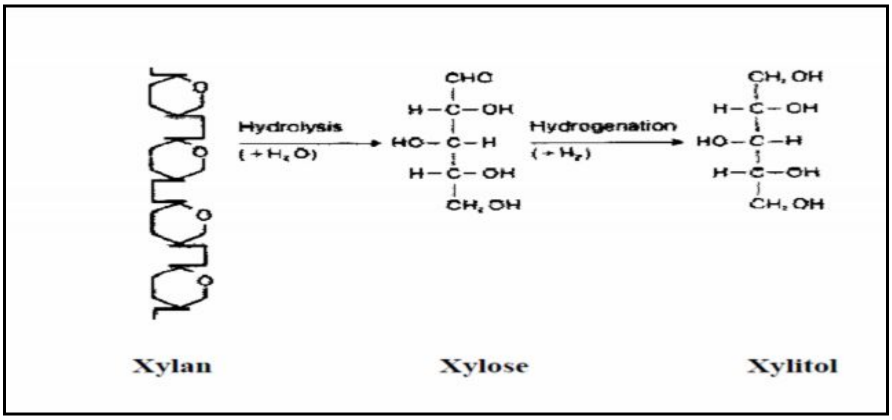


Fig 4. Hydrolysis and hydrogenation of xylan to xylitol (Counsell, 1978)

Detoxification procedure

After these treatments, the hydrolysate was mixed with 10% activated charcoal, agitated (200 rpm, 30 ˚C,1 h) and then filtered. The filtrate was autoclaved at 120˚C for 15 min. Filtrate (Water hyacinth hydrolysate) was used in fermentation for xylitol production.

Fermentation

The development of economic fermentative process for xylitol production involves the selection of microbial yeast strains with high productivity, the establishment of conditions that maximize the conversion of xylose to xylitol, and optimization of these parameters for process scale up [55]. Xylitol was the main metabolite formed during the xylose fermentation by yeasts. The hydrosylates were supplemented with 2.0 g/l peptone, 3.0 g/l yeast extract, 1.0 g/l $(NH_4)_2SO_4$, 2.0/l KH_2PO_4 and 1.0g/l $MgSO_4.7H_2O$. Batch fermentation was conducted in 250 Erlenmeyer flask with a working volume of 50 ml. The fermentation medium was inoculated with 24 h old, 2% v/v inoculums. The fermentation was carried out at 32 ˚C, pH 5.7 and 250 rpm for 72 h. Samples were taken at regular intervals to determine the concentrations of xylitol and remaining xylose in hydrolysate.

Yield and Efficiency

Xylose conversion efficiency was upto 63.4 % in case of the hydrolysate obtained from corn husk with xylitol yield 0.44 g/l h under optimal conditions[56], 92 % efficiency was obtained using Eucalyptus wood with yield of 0.84 g/g [57], 90% efficiency from corn husk with yield of 35 g/l xylitol from 40 g/l xylose[58] and maximum xylitol was obtained from wheat straw was 0.89 g xylitol/g xylose with conversion efficiency 97 %[59]. Xylitol concentration of 32.5 g/l was obtained after 48 hr of fermentation, with a yield of 0.65 g xylitol/g xylose from water hyacinth biomass[60]. Further optimization of xylose sugar and xylitol production from water hyacinth biomass is the objective of the present study.

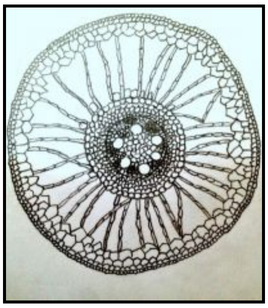
Discussions:

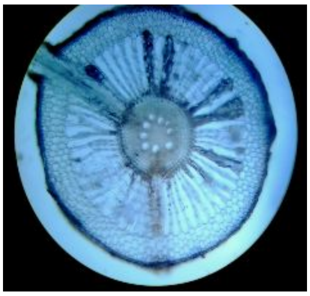
Anatomical Study

The fresh plant parts i.e. rhizomes, roots, leaves and petioles were collected. Manual sectioning was done to study the plant material in cross sections and transverse sections.

Root

Root epidermis consists of rectangular cells, single layered, compact cuticle found on the outside of root epidermis as shown in Fig. 5a-b. Hypodermis is composed of 1-2 layers of thick-walled cells. Cortex is differentiated into outer and inner cortex. The outer cortex is composed of 3-4 layered parenchymateous cells. Each air space has trabeculae or partitions of parenchyma cells. The inner cortex consists of 6-10 layers of parenchymateous cells. There is no sclerenechyma cell in the cortex. The stele is surrounded on the outside by single layered endodermis where Casparian strips are not prominent. Single-layered pericycle is present under the endodermis. The stele consists of 7-10 xylem bundles alternating with phloem bundles. Each vascular bundle consists of a single metaxylem vessel surrounded smaller vessels. The root center is occupied by sclerified parenchyma cells.





(a) **(b)**

Fig 5 : (a) Schematic Diagram of T.S of Root of Water hyacinth, (b) Microscopic view of T.S of root of Water hyacinth

Rhizom

The single layered epidermis, with compactly arranged rectangular cells. The cortex under the epidermis consists of 4-6 layered "outer cortex" with cortical cells having dispersed different size vascular bundles surrounded on the outside by a patch of sclerenechyma. Air spaces are also prominent in this cortex. Xylem is V shaped. Phloem is present in between the arms of the xylem. Empty spaces or xylem cavities made up of lysed protoxylem elements are also visible as shown in Fig. 6. There is an inner portion of large air spaces separated from each other by a single cell layer of parenchyma. Air spaces are spherical. Vascular bundles are also present in the center of rhizome

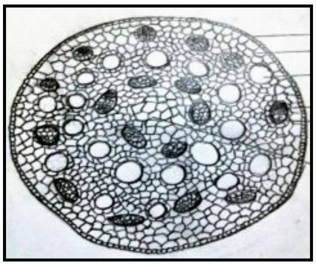
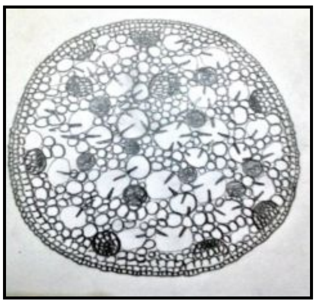
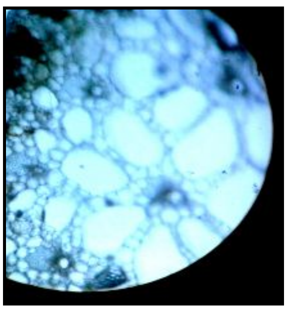


Fig 6 : T. S of Rhizome

Petiole / Stem

Epidermis of petiole is also single layered and composed of parenchyma cells as represented by Fig. 7a-b. Cuticle is absent. Vascular bundles are embedded in outer parenchyma cells. Each vascular bundle has a bundle cap of sclerenechyma cells making up the petiole. The hexagonal air spaces are surrounded by bands of single layered parenchyma cells as shown in Vascular bundles are immersed in aerenchyma. Each vascular bundle has xylem tissue consisting of tracheids, vessels, parenchyma cells and fibers. Phloem is composed of sieve tubes and companion cells. Sclereids were observed arising from aerenchyma cells projecting into air spaces. A few raphides were also observed in parenchyma cells.





(a) **(b)**

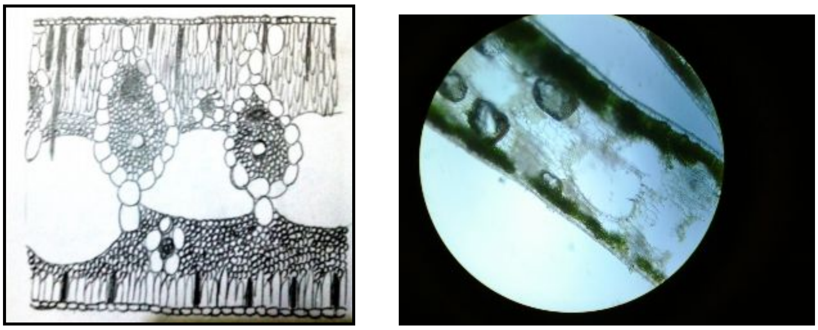
Fig 7 : (a) Scematic diagram of T.S of Stem/Petiole of water hyacinth, (b) Microscopic view of T.S of petiole/stem of water hyacinth

Leaves

Epidermal peels of leaves were studied. Trichomes are not observed in epidermis. Stomata are of paracytic type.

Transverse section

Leaf lamina has a thin cuticle on the epidermal cells, which are rectangular and single layered as described by Fig. 8a-b. The mesophyll is differentiated into a palisade and spongy mesophyll. Palisade layer is present on both upper and lower side beneath the epidermis. The upper epidermis has 5-7 layers of cells and the lower epidermis has 2-3 layers. Inside the palisade layer are densely staining material which may be supportive in nature. The spongy mesophyll consists of a large number of air spaces surrounded by thin walls full of chloroplast. Sclereids are observed in cells facing air spaces. Vascular bundles are of two types, i.e. smaller and larger vascular bundles. Smaller vascular bundles are present in both upper and lower epidermis side; some of them are in contact with the epidermis. Each vascular bundle is collateral with xylem towards the lower epidermis side and phloem towards the upper epidermis side. Tracheary elements consist of tracheids, vessels, and parenchyma cells. Tracheary elements in smaller bundles are thin-walled and without usual secondary thickenings. The phloem consists of sieve tubes and companion cells. Bundle sheath extensions are also observable in smaller bundles. Large vascular bundles are present in the leaf center and extend from one end to the other of the leaf. Each vascular bundle is surrounded by a bundle sheath of parenchyma cells. Sclereids are present in the palisade cells, and also in air spaces.



(a) (b)

Fig 8 : (a) Schematic diagram of T.S of Leaf of water hyacinth, (b) Microscopic view of T.S of water hyacinth

Conclusion

Xylitol being an extremely important constituent in food and pharmaceutical industries, the production should be higher with minimum cost for better access to people. Bioconversion pathway from lignocellulosic biomass is a good alternative. Biological production using yeasts is very effective, but maintenance of proper growth condition is crucial for production. Water hyacinth Biomass has a high hemicelluloses content, resulting in high xylose yield, suitable for conversion to xylitol. Water hyacinth is one of the common weed abundantly available worldwide, causing major problem to aquatic ecosystem due to invasive growth. An added advantage of using WHB is that it is not edible. The hemicelluloses present in WHB can be hydrolysed to obtain xylan sugar which can be fermented to xylitol. Many studies were done on this pretreatment process as chemical, physico-chemical and biological process. To obtain this value added product xylitol effectively from WHB with low cost for cheap availability, biological process are considered, which is overall an eco- friendly process.

Acknowledgements

The authors express their gratitude to the Director C.M.E.R.I. & Director N.I.T. for their kind support to carry out the research.

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