ENZYMATIC RECOVERY OF WATER FROM WATER HYACINTH

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ABSTRACT: This study sought to assess the viability of utilizing water recovered from a declared aquatic weed, *Eichhornia crassipes*, commonly known as the water hyacinth, for domestic, industrial and agricultural purposes. Celluclast, Pectinex Ultra SP-L and Tween 80 were utilized to chemically extract water from pulp retrieved from water hyacinth. The largest yield (88±3 wt%) was obtained in combining a mixture of the two enzymes (Celluclast and Pectinex Ultra SP-L) with an additional 140 ml of water at a pH of 4 and temperature of 37.5ºC. The extracted water was found to be suitable for agricultural and industrial purposes. Activated carbon and sediment filters had a reducing effect on most of the elements analysed, but not on the levels of the total dissolved solids (TDS) present in the water. It is recommended that further water purification processes will have to be implemented before such water is feasible for domestic purposes.

Keywords: biomass, enzymatic process, water use

1 INTRODUCTION

Utilization of fossil fuels to generate energy currently contributes to 84% of the global energy demand. As a result of projections that indicated the depletion time of fossil fuel resources to be roughly 110 years, worldwide research is being conducted concerning the development of alternative, sustainable energy sources [1].

Furthermore, according to the UN, water scarcity already affects every continent on earth and around 1.2 billion people live in areas of physical water scarcity while another 500 million people are approaching this situation. During the last century, the world population has tripled and is expected to rise from the current 6.5 billion to 8.9 billion in 2050, while the water demand has been growing at more than twice the rate of the population increase [2].

South Africa is regarded as semi-arid with a mean annual rainfall of approximately 450 mm, however, it is unevenly spread throughout the country [3]. As a result of this water scarcity, it is of utmost importance to investigate any available water sources in the arid areas which are not yet being utilized. According to Statistics South Africa, the South African human population has increased from around 40 million in 1996 to around 50 million in 2011. As a result of this 25% increase in human population over a period of 16 years, the demand for water also increased [4]. Employment of invasive aquatic weeds may serve as a possible contributor to the solution of both the energy- and water crisis.

1.1 Background

Originating from the state of Amazon, Brazil, the water hyacinth has spread around the globe invading Africa, Asia and North America, while occurring in at least 62 countries by 2010 [5]. The water hyacinth is one of the world's worst aquatic weeds, infesting rivers, lakes, dams and irrigation channels on every continent with the exception of Antarctica.

Water hyacinths are succulent plants with a high lignocellulosic content. Water hyacinth plants are unique in their ability to efficiently store water in their tissues. A typical mature water hyacinth plant has a basic structure, perfect for efficient water storage, that consists of hairy roots, rhizomes, stolons, broad leaves, inflorescences and fruit clusters [6]. Even though the plant has two types of leaves (leaves with non-bulbous petioles and leaves with bulbous petioles) both are smooth, hairless and glossy. Leaves with non-bulbous petioles are narrow, erect and up to 60 cm long – typical of plants in dense, packed infestations, while leaves with bulbous petioles are thick stemmed and circular with a diameter up to 30 cm. These thick leaves contain variable amounts of air which enable the hyacinth to float and will be found on the edge of an infestation or in open water [7].The two types of stems consist of erect stems growing up to 60 cm long with flowers and horizontal vegetative stems (stolons, 10 cm long) which produce new daughter plants. Seeds (1 to 1.5 mm long and egg shaped with ridges) are prolonged and it is possible that seeds may germinate after 20 years of being dormant in mud.

Flowers are funnel-shaped, dark blue or bluish-purple with a yellow centre and grow 4 to 7 cm across while each flower has six distinctive petals that serve as protection. The flowers are located on the upright stems of the plant and each spike usually contains 8 flowers.

The fibrous, unbranched roots can be up to 1 m in length, have a conspicuous root cap and are purplish of colour whilst exposed to sunlight and white when in darkness or rooted in soil [6]. Rhizomes are that part of the vegetative stem that consists of an axis containing short internodes. All the roots, leaves, offshoots and inflorescences are produced at the numerous nodes.

1.2 Impacts on surroundings

Being called the world's worst aquatic weed is the result of the water hyacinth's ability to rapidly cover large areas of water. The water hyacinth has a variety of impacts which include the following:

- blockage of irrigation channels and rivers
- livestock have restricted access to water
- natural wetlands are destroyed
- native aquatic plants are threatened and eliminated
- the infiltration of sunlight into the water is reduced
- during floods it is possible that large hyacinth mats may become mobile destroying fences, roads, pastures and crops [7].

1.3 Control techniques

It is difficult to control the water hyacinth in all freshwater aquatic environments due to its ability to reproduce and spread rapidly. If a detected hyacinth infestation is not treated as soon as possible, the cost and duration of the eradication program will be drastically increased [7]. Control techniques include physical, biological and chemical control.

Physical removal of water hyacinths, with pitchforks and household tools, on small scale such as farm dams and drains is only effective when the rate of removal is greater than the rate of re-growth. On a larger scale it is likely that mechanical removal will be the choice of control, although costly. It takes roughly 600 to 900 hours to harvest one hectare of dense water hyacinth, while it is essential for the harvesting to be completed prior to flowering and seed set. Every year the White Nile River is cleansed of fifty million tonnes of water hyacinth through mechanical harvesting [8].

A study was completed on the biological control of water hyacinths at the University of the Witwatersrand, Johannesburg, with the addition of a herbivory mirid (*Eccritotarsus catarinensis)*. The purpose of this study was to determine the competitive interactions between water hyacinths and water lettuce in the presence of a sap feeding mirid that removes chlorophyll from plants. Results indicated that the water hyacinth was at least 23 times more competitive than water lettuce in absence of the herbivory, while only 10-fold greater with sustained damage caused by the mirid [9]. Utilization of biological control agents in the form of two weevil species, *Neochetina eichhorniae* and *Neochetina bruchi,* are another possibility [7].

Application of herbicides with the purpose of controlling weeds is commonly used in both agricultural and non-agricultural situations. Herbicides achieve their purpose by interfering with the growth of the plant, replacing hormones in the plant and by blocking chemical reactions. Current herbicides are categorized as contact herbicides and translocated herbicides.

Contact herbicides destroy the parts of the plant they make contact with, which is usually the leaves and stems of the weed. Depending on the amount of weed species, contact herbicides can be either selective or non-selective. In order to achieve effective results, good coverage over the weed infestation is required [7].

Translocated herbicides move within the plant to a site of action, disrupting growth processes and interfering with biochemical reactions. Areas of the plant where cells are actively dividing in growth tissue are usually where these herbicides take action. Such areas include the bases of stems in grass and in growing tips or buds in broadleaf weeds such as the water hyacinth [7].

1.4 Harvesting

The Vaal River located in the midlands of South Africa, originates in the eastern highveld plains in the vicinity of a town known as Ermelo, established in the Mpumalanga province, from where it flows through multiple towns to meet the Orange river approximately 1200 km downstream. Parys is one of the small towns, situated in the Free State province, through which the Vaal River passes [10].

Currently both fisherman and members of the community merely remove water hyacinth plants physically from the Vaal River, usually allowing them to perish in the sun. As a result of the high nutrient and protein contents of the water hyacinth, farmers have utilized the plants for agricultural purposes such as feed for livestock as well as fertiliser for nutrient deficient soils.

1.5 Chemical extraction

As already mentioned, water hyacinth has a high lignocellulosic content which can be divided into three main components: lignin (10%), cellulose (20%) and hemicellulose (33%) [11]. The cellulose, hemicellulose and lignin in lignocellulosic material are linked to form a strong structure which is difficult to process in raw conditions. Thus pretreatment is required to render the components neccesary for further exploitation leading to enhancement of the hydrolysis process. A study indicated that water hyacinth have an average water content of approximately 93%, however chemical pretreatment is required to achieve the successful extraction of water [12]. Such pretreatment may be performed with a variety of enzymes including cellulase and pectinase. A previous study proposed that a combination of pectinase with amylase and mash enzyme utilized in the recovery process of kiwifruit juice increased the juice yield from 58.44 % up to 78.46 % [12]. Surfactants such as Tween 80 may also serve as a possible extraction agent.

The possibility of purifying the extracted water with a reverse osmosis process may be investigated in the future to determine the economic feasibility.

2 MATERIALS AND METHODS

2.1 Materials

Water hyacinths (*Eichornia crassipes*) were harvested from the Vaal river in the Parys area. The hyacinths were prepared for the relevant experiments by removing the roots from the rest of each plant and juicing the stem and leaf to a pulp medium.

2.2 Chemicals

Enzymes used were Celluclast 1.5 L (Novozymes), with a 15 wt% glucose content, and Pectinex Ultra SP-L, with a 5 wt% polygalacturonase conent. The Surfacant Tween 80 (Merck), with a saponification number of 45 – 55 mg KOH/g and a hydroxyl number of 65 – 80 mg/g was used. The alkaline solution NaOH (98%, Labchem) and acid solution H_2SO_4 (98%, Labchem) were used to adjust the pH to the desired level for each experiment. The chemicals were used as provided and no further purification was done.

2.3 Experimental methods

2.3.1 Harvesting

Water hyacinth was harvested using kayaks. The biomass was transported in a sealed trailer back to the North-West University where the juicing process commenced.

2.3.2 Formation of pulp medium

The procedure for chemically extracting water from water hyacinth consisted of two stages. During the first stage, the roots of the hyacinths were removed after which the stems and leaves of the hyacinth plants were juiced with a Russel Hobbs blender to form a pulp medium. Juicing harvested water hyacinth plants with a Russel Hobbs blender produced a pulp medium resulting in a higher contact area for the extraction agents added along with an increase in the amount of polysaccharides (including pectin and cellulose) extracted from the pulp to the liquid product [12].

2.3.3 Moisture content

In order to determine the moisture content of the water hyacinth, five separate samples were prepared. These samples each included 100 g of water hyacinth pulp placed on an hour glass for 24 hours at a temperature of 105 □C. The dry matter of each sample was weighed to calculate moisture content.

2.3.4 Optimal oven times

From a previous study it was found that the optimal oven time for the experiments were approximately an hour after which the temperature was increased to 99 □C for ±20 minutes. This increase in teperature was to allow for the denaturation of the chemical additives.

2.3.5 Chemical extraction of water

The second stage entailed the extraction of water from the hyacinth pulp via three extraction agents. Although each extraction agent possesses a unique ability to extract the water, the experimental methods were identical for both enzymes (Celluclast 1.5 L and Pectinex Ultra SP-L) and the surfactant (Tween 80). The first step for every experiment conducted, was to fill a Duran flask (1000 ml) with 100g of hyacinth pulp. The temperature and pH were the two variables throughout the procedure. A Scientific Series 2000 was used to maintain the predetermined temperature while the pH was adjusted using NaOH and H_2SO_4.

The influence of temperature and pH on the extraction process was investigated to determine the optimum conditions for extraction of water from the hyacinth pulp. A constant dosage of the extraction agent was maintained throughout every experiment. Enzymatic experiments were performed with a dosage of 0.07 g (0.07 wt%) for both Celluclast 1.5 L and Pectinex Ultra SP-L while a dosage of 0.125 g (1.25g/kg) of the surfactant Tween 80 was used.

The pH dependant experiments were executed at a constant temperature of 40 °C while the pH was predetermined for five different experiments, ranging from pH 2.5 to 6.5. Conversely the temperature dependant experiments were conducted at a constant pH of 4.5. The predetermined temperatures for the five experiments ranged from 30 °C to 50 °C.

Each experimental sample remained in an oven for one hour at the specified temperature and pH. Enzymes start to denaturate at a temperature higher than 40 °C, thus after an hour the oven temperature was increased to 99 °C for 20 minutes to allow for the denaturation, which ensured no enzymes were present during analysis executed on the samples. After the cooling period, the solids were separated from the water using a Büchner filter.

In addition to the standard experiments conducted, a specific set of samples were prepared which included additional water added during the preparation phase prior to placing the samples in the oven. The addition of water possibly increased the active area of the additives reacting with the pulp medium. Thus the additives would be present throughout the water hyacinth pulp as the addition of water served as a dispersion agent regarding the additives.

2.3.6 Purification

An additional purification step was introduced to the study. This step included an activated carbon- and sediment filter, each with unique characteristics and relatively inexpensive. The purpose of this stage was to establish the effects of such filters on the water quality in comparison to unfiltered water. These filters were provided by RST – Water Saving Systems [13]. Sediment filters specialise in the removal of suspended materials causing turbidity in water such as sand, silt and loose clay. Microbial contaminants are usually not removed by sediment filters, thus requiring additional purification stages one of which may be microfiltration and activated carbon filtration [13]. Activated carbon filters effectively reduce the amount of organic compounds such as benzene and toluene present in the water. Bad tastes and odours as well as the levels chlorine and radon present in the water will be reduced by an activated carbon filter [14].

2.3.7 Measurables

The water quality was determined by sending water obtained through the chemical extraction process to the Envirocare Laboratory in Potchefstroom which specialises in the elemental analysis of water.

The total dissolve solids (TDS) levels of the extracted water were measured by making use of a Hanna TDS Tester. The yield was determined by weighing the mass of the water obtained after the filtration step was completed.

3 RESULTS AND DISCUSSION

3.1 Moisture content

The moisture content of water hyacinth was determined by the measurement of wet and dry mass respectively. Preparation of these samples included the cutting and juicing of fresh hyacinth pieces to form a pulp medium which is easier to handle. The average moisture content was calculated to be 93.24±0.75 wt%.

3.2 Optimum oven time

To determine the oven time for the chemicals to react optimally, three water hyacinth pulp samples were prepared for each of the three additives (Celluclast 1.5 L, Pectinex Ultra SP-L and Tween 80). It was of great importance to establish this parameter prior to any other due to the fact that this parameter had an influence on every subsequent experiment involving pH and temperature dependencies. Figure 1 displays the weight percentage water obtained for the three additives at various oven times respectively.

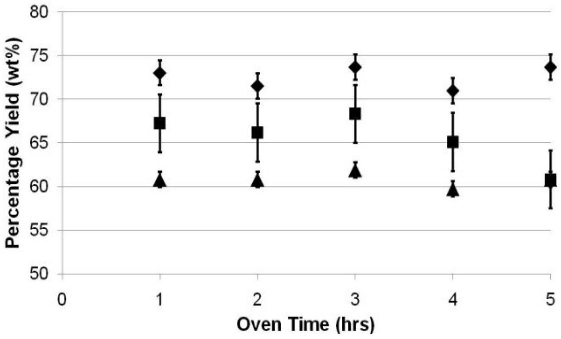

Figure 1: Optimal oven times for the three additives (◆ Celluclast; ■ Pectinex Ultra SP-L; ▲ Tween 80)

From Figure 1 it is clear that after an hour the amount of water yielded remained relatively constant for each additive with no drastic effects as the oven time increased. All the experiments were performed at the respective optimum process conditions relating to the three substances added to the pulp. The average yield obtained for the Celluclast, Pectinex Ultra SP-L and Tween 80 experiments were 73±1.44, 66±3.33 and 61±0.87 wt%.

3.3 Yield

During this experiment, the yield served as an indication of the maximum amount of water that can be extracted under various process conditions. Figure 2 exhibits the water yield for the respective pH dependant experiments conducted using two enzymes and a surfactant.

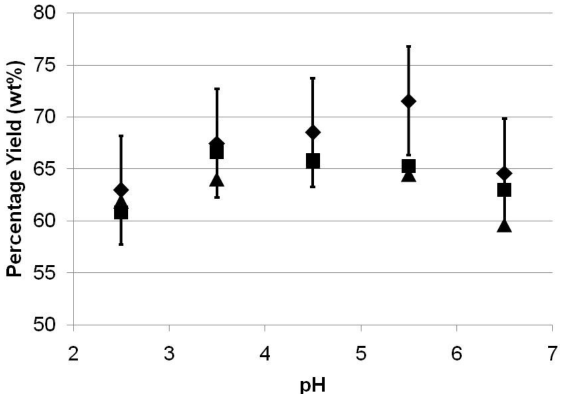

Figure 2: Water yield for the pH dependant experiments (◆ Celluclast; ■ Pectinex Ultra SP-L; ▲ Tween 80)

It is clear from Figure 2 that the variation in the pH level has a significant effect on the water yield. The optimum pH level for Celluclast, Pectinex Ultra SP-L and Tween 80 are pH 5.5, 3.5 and 4.5 respectively. Celluclast shows an increase of approximately 12% in the yield as the pH level increases from 2.5 to 5.5, after which it starts to decrease. The yield for the other two substances remained relatively constant. The average yield acquired for Celluclast, Pectinex Ultra SP-L and Tween 80 were 67±5.25, 64±7.84 and 63±6.82 wt% respectively. The largest yield obtained in this set of experiments was through the addition of Celluclast at a pH of 5.5, which produced a yield of 73 wt%. As a result of the experimental method being exactly similar for the experiments involving the different additives, the experimental errors calculated were relatively analogous. Thus from Figure 2 it is visible that the experimental error bars of Celluclast only was indicated. This set of experiments was carried out using pulp with a stems to leaves ratio of 1:1.

Figure 3 represents the water yield obtained for experiments regarding variation in temperature.

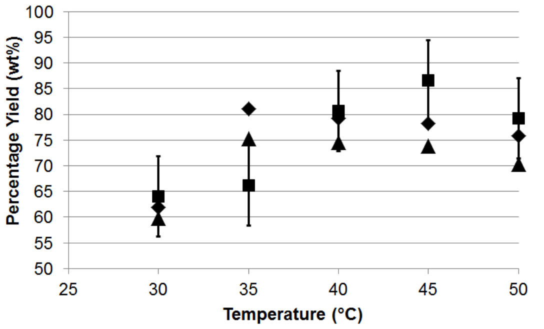

Figure 3: Water yield for the temperature dependant experiments (◆ Celluclast; ■ Pectinex Ultra SP-L; ▲ Tween 80)

Both Celluclast and Tween 80 produced a maximum yield, of 81 wt% and 75 wt% respectively, at 35 °C, while Pectinex Ultra SP–L generated the highest yield of 86.55 wt% for the series of experiments. This value of Pectinex Ultra SP–L is regarded as an outlier, at a temperature of 45 °C, due to the large difference in yield and this value does not comply with the predicted optimal temperature of 40 °C. The average yield achieved for Celluclast, Pectinex Ultra SP–L and Tween 80 were 75±5.25, 75±7.84 and 70±6.82 wt% respectively. The pulp employed to achieve these results had an approximate stems to leaves ratio of 9:1. Both the Celluclast and Tween 80 trends satisfy the Arrhenius equation as it is dependent on temperature. As a result it is clear that hyacinth leaves contain less water than stems, as the water yielded from pulp, largely consisting of stems, was approximately 10% higher than pulp consisting of approximately 50% stems and 50% leaves.

Figure 4 displays the water yielded from experiments conducted, concerning the variation in pH of samples treated with a combination of the enzymes, Celluclast and Pectinex Ultra SP-L.

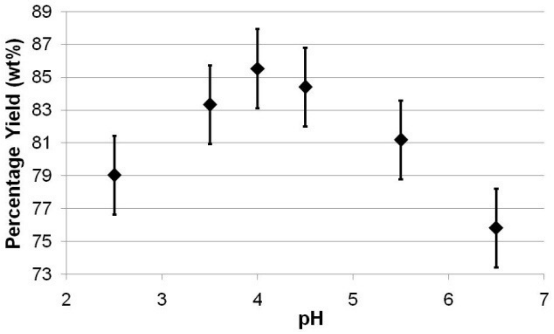

Figure 4: Water yield for the pH dependant experiments treated with combination of Celluclast and Pectinex Ultra SP –L (◆Celluclast + Pectinex Ultra SP-L)

From Figure 4 it is clear that the experiments conducted at a pH of 4 generated the highest yield of approximately 86wt%. The trend indicates an increase as the pH increases up to the optimal point (pH of 4) where after it decreases. The average yield of 82 ± 2.35 wt% was obtained from pulp with a stems to leaves ratio of approximately 9:1.

Figure 5 represents the water yielded from experiments conducted, regarding the variation in temperature of samples treated with a combination of the enzymes; Celluclast and Pectinex Ultra SP-L.

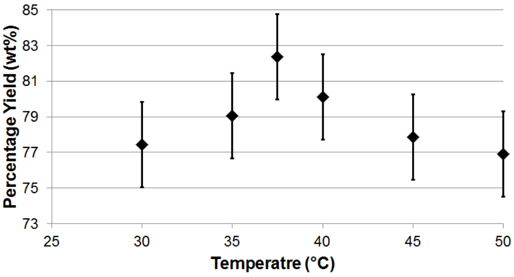

Figure 5: Water yield for the temperature dependant experiments treated with combination of Celluclast and Pectinex Ultra SP-L (◆Celluclast + Pectinex Ultra SP-L)

The trend for this set of temperature dependent experiments, pretreated with the combination of enzymes, is similar to that of the pH dependant experiments. Once again the maximum yield is delivered at the predicted process conditions (37.5 °C), however the yield is slightly lower (±82.5 wt%). The average yield of 79±2.35 wt% was achieved from a pulp consisting of a stems to leaves ratio of 9:1.

A higher yield was obtained from the experiments conducted with a combination of Celluclast and Pectinex Ultra SP-L in comparison to the experiments where the enzymes were employed separately. The reason for this higher yield may be the result of the two enzymes complimenting each other. Celluclast specializes in the breakdown of cellulosic materials while Pectinex Ultra SP-L breaks down the pectin in the cell walls of the water hyacinth plants [16]. Pectinex Ultra SP-L which is a mixture of enzymes also contains small amounts of hemicellulases and cellulases [17]. Thus it can be concluded that the employment of a combination of these two enzymes increases the efficiency of the water extraction process.

Figure 6 exhibits the effect that the addition of supplementary de-ionized water as well as recycled water have on the amount of water yielded from the experiments respectively.

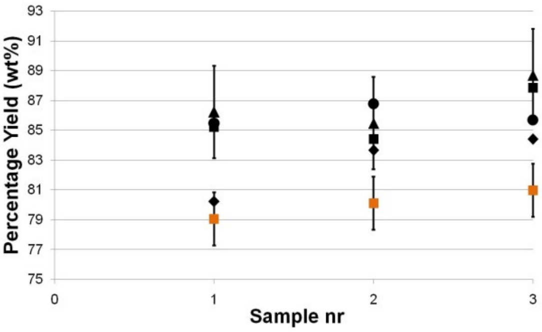

Figure 6: Water yield for experiments regarding the addition of supplementary water to the samples pretreated with Celluclast, Pectinex Ultra SP-L and Tween 80 (◆ Celluclast; ■ Pectinex Ultra SP-L; ▲ Celluclast + Pectinex Ultra SP-L; ● Celluclast + Pectinex Ultra SP-L + recycled water; 🟧 Tween 80)

From Figure 6 it can be concluded that the addition of supplementary water increased the average yield of water with up to 15%, compared to experiments excluding additional water. The addition of water increased the contact area of the additives with the water hyacinth pulp, resulting in an increase in the active area of the additives. Accordingly the water yield increased with approximately 16% as mentioned. It is visible that the addition of water to the experiments containing the combination of Celluclast and Pectinex Ultra SP-L delivered the highest average yield of 86.8±3.1 wt%. The maximum yield obtained as 88.70 wt%/wt was obtained from such a sample. Recycled water used in experiments with a combination of the two enzymes did not have an increasing effect on the yield. The average yields obtained for the Celluclast, Pectinex Ultra SP-L, Tween 80, and Celluclast + Pectinex Ultra SP-L + recycled water were 83±4.1, 86±3.3, 80±1.77 and 86±1.27 wt%.

Figure 7 represents a summary containing the yields obtained from experiments conducted with and without additional water.

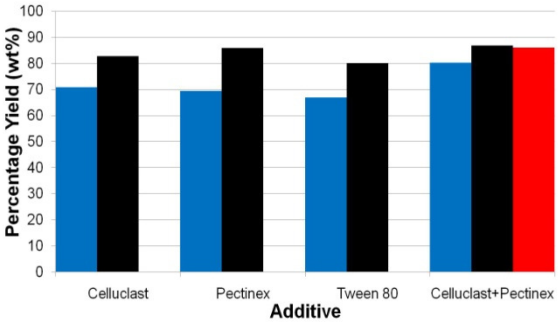

Figure 7: Summary of experiments conducted both with and without water (🟦 no additional water; ■ with additional water; 🟥 with recycled water).

From Figure 7 it is clear that in comparison, the addition of extra water during preparation of the samples had a considerable increasing effect on the water yield. Experiments conducted by using a combination of the two enzymes yielded the highest amount of water, however lower than expected. Throughout the multiple series of experiments carried out, Tween 80 revealed to deliver the smallest average yield, while Pectinex Ultra SP-L generated the highest average yield when the substances were used separately. The overall average yields obtained for Celluclast, Pectinex Ultra SP-L and Tween 80 without additional water were 70.8±4.88, 69.5±7.2 and 66.9±6.46 wt% respectively. Average yields acquired from Celluclast, Pectinex Ultra SP-L and Tween 80 experiments with additional water were 82.8±5, 85.82±3.4 and 80±1.8 wt% respectively. The average yields obtained from the mixture of Celluclast and Pectinex Ultra SP-L without and with additional water were 80±2.5 and 86.8±3.16 wt% while the average yield attained from the addition of recycled water was 86±1.26 wt%.

The detergent Tween 80 belongs to a group of compounds known as surfactants [14]. Surfactants are surface active agents that reduce the interfacial surface tension in mixtures through adsorbing to the interfaces. Experimental results proved that Tween 80 was the least effective extracting agent in comparison to the two enzymes. The lignocellulosic nature of water hyacinths, may be the reason for the weak extraction as Tween 80 does not have the ability to break down the cellulosic and pectinolytic compounds present in the water hyacinth plants.

3.4 Water quality at optimum conditions

The quality of the water obtained via chemical extraction methods is important as it determines whether the water can be applied as well as the type of application. Multiple factors including the total dissolved solids (TDS) level, pH, total hardness, sodium adsorption ratio and the concentration of certain constituents such as metals have to be taken into consideration.

3.4.1 pH

Being one of the variable process conditions, the pH level was controlled via chemical additives (H_2SO_4 and NaOH) in order to achieve the optimal conditions for water extraction. Although the pH of every experiment conducted was measured, it was not the determining factor for the choice of application.

3.4.2 TDS

The DWAF defined total dissolved solids (TDS) as a measure of the amount of assorted inorganic salts dissolved in water. As a result of the TDS concentration being directly proportional to the electrical conductivity (EC) of water and since EC is much easier to measure than TDS, it is used as an estimation of the TDS concentration. Electrical conductivity (EC) is best described as a measure of the ability of water to conduct an electrical current due to the presence of ions in the water.

TDS of most natural waters is related to the dissolved salt concentration in the water through a conversion factor ranging from 5.5 to 7.5. The average acceptable conversion factor for most waters is 6.5 and the conversion equation is as follows:

$$TDS\left(\frac{mg}{L}\right) = EC\left(\frac{mS}{m}\right) \times 6.5 \qquad (3.1)$$

The average TDS value calculated for unfiltered water yielded at optimal process conditions were approximately 8940±79.5 mg/L. According to the DWAF, the target TDS levels for industrial and domestic water range from 0 to 100 mg/L and 0 to 450 mg/L respectively. The target TDS levels in water used for irrigation are 260 mg/L. Thus the calculated TDS levels are well above the target ranges provided and the use of such water will not be without the possibilities of health effects, scaling and interference with processes [12].

Filtration was performed with both a sediment and activated carbon filter in order to reduce the levels of the contaminants as much as possible. Sediment filters remove suspended matter such as sand, slit and organic material from water while activated carbon filters reduce the amount of ions and metals such as chlorine and radon[14]. These filters are known as pre-filters due to the fact that they are implemented prior to a reverse osmosis membrane in water treatment systems [15]. Reverse osmosis systems on the other hand, reduce the total dissolved (TDS) levels in the water as well as the suspended particles within the water [15]. By assessing the capabilities of the two filters implemented during the filtration process, it can be concluded that the TDS levels in the water would not be affected.

3.4.3 Metals

To determine the macro-elements characterizing the water hyacinth, a sample of the water extracted at optimal conditions was sent for a full compositional analysis. Another sample filtered through sediment and carbon filters, provided by RST Water Saving Systems, was sent for an identical analysis. The results obtained from both analyses served as an indication of the notable elements as well as the effects of the filters implemented.

The elements in the unfiltered sample demonstrating a quantity larger than 0.5 mg/L are presented in Table I along with the respective filtered concentrations of every element.

Table I: Metals displaying notable quantities in the tested samples

Metal	Quantity Unfiltered [mg/L]	Quantity Filtered [mg/L]
K	372.9	91.3
Mg	25.56	0.5803
Na	12.79	9.286
Ca	9.391	0.0015
Mn	7.652	0.1134
Rb	3.147	0.6877
Cu	0.9893	0.0426
Fe	0.5706	0.0098

The analysis conducted on both water samples included measurement of sodium (Na), magnesium (Mg), potassium (K) and calcium (Ca). Ca and Mg levels were measured with the purpose of calculating the total hardness as well as the sodium adsorption ratio of the extracted water. According to Rand Water, South Africa, the notable presence of the metals iron (Fe), copper (Cu), rubidium (Rb) and manganese (Mn) may be the result of gold mining and industrial impacts on water in the Vaal Barrage area near Parys where the water hyacinth was harvested.

3.4.4 Total hardness

The scale-forming and corrosive potential of water is directly related to the equilibrium saturation point of the water and may have significant impacts on irrigation systems utilizing such hard water. Total hardness of water may be described as the combined concentrations of magnesium and calcium present in the water and is usually expressed as mg $CaCO_3$/L. The total hardness of water may be calculated with the following equation provided by the DWAF:

$$\text{Total hardness (mg } CaCO_3\text{ /L)} = 2.497 \times [\text{mg Ca/L}] + 4.118 \times [\text{mg Mg/L}] \qquad (3.2)$$

Total hardness levels obtained from experiments conducted at optimal process conditions indicated the average levels of unfiltered and filtered water are 130±5.4 mg/L and 2.5±0.061 mg/L respectively. These levels comply with both industrial as well as domestic standards set by the DWAF, however no standards have been published concerning agriculture. Thus the respective categories relating to unfiltered and filtered water are slightly hard and soft.

3.4.5 Sodium adsorption ratio (SAR)

Soil sodicity is the percentage of a soil's cation exchange capacity occupied by sodium ions. The sodium adsorption ratio (SAR) is an indication of the potential of particular irrigation water to induce sodic soil conditions. SAR is calculated from the sodium, calcium and magnesium concentrations present in the water and provide an indication of the level where the exchangeable sodium percentage (ESP) of the soil will stabilize after extensive irrigation [14].

Implementation of SAR is, in South Africa, applicable to irrigation water only, thus guidelines concerning SAR provided by DWAF relate to agriculture only. The SAR of irrigation water may be calculated with the following equation:

$$SAR = \frac{[sodium]}{\sqrt{0.5([calcium] + [magnesium])}} \tag{3.2}$$

with the sodium, calcium and magnesium concentrations present in the solution measured in mmol/L [14]. As SAR is only a ratio, the use of units is irrelevant.

With the optimal SAR equaling two or smaller, the SAR levels obtained for the unfiltered water satisfy the provided irrigation guidelines with an average value of approximately 0.36±0.01. However the SAR for filtered water experiments indicated an average trend of 15±1.04, which may result in sodium-sensitive crops absorbing toxic levels of sodium through root uptake. Although this may pose to be a threat to crop yield, there are a number of economically important crops that can be irrigated without developing sodium toxicity [14]. Infiltration problems are more likely to occur in soil irrigated with such water.

3.4.6 Salinity

Salinity is a measure of the salt content (including sodium and potassium salts) of a given quantity of water or soil. Accumulation of such salts in the root area of plants may have radical effects on the growth yield of horticultural crops, whereas a high concentration salts could possibly kill plants.

The average potassium concentrations obtained for the unfiltered and filtered experiments were 376±8.5 mg/L and 96±9.5 mg/L which is well above the optimal salinity range for domestic water which ranges between 0 and 50 mg/L. Guidelines concerning impacts of potassium on the domestic sector are provided, conversely none is available regarding the industrial and agricultural sectors. High potassium concentrations in the water may result in the water having a noticeable bitter taste and cause electrolyte disturbances in sensitive individuals [19].

The average sodium concentrations acquired for the unfiltered and filtered experiments were 12±0.6 mg/L and 9±0.4 mg/L respectively and within the domestic target range of 0-100 mg/L specified by DWAF [18]. Such low levels of sodium in the water have no aesthetic or health effects. With an agricultural sodium target range concentration of 0-70 mg/L, utilization of such water for irrigation should prevent the accumulation of sodium to toxic levels in most crops with the exception of extremely sensitive plants [19].

3.4.7 Phosphorus

The implementation of mineral phosphorus fertilizer enabled crop farmers around the world to replenish the phosphorus lost from the soil during the harvesting process of crops. Since the use of phosphorus in fertilizers, substantial increases in the agricultural yields have been observed. In the world of today, food production has become extremely dependant on the use of phosphorus fertilizers, however it may be considered an unsustainable development due to the fact that phosphorus rock deposits are finite [20].

The phosphorus concentrations present in the extracted water indicate oligotrophic conditions as classified by the DWAF to have a phosphorus concentration of less than 5 mg/L. The average unfiltered water displayed an average phosphorus concentration level of 104±5.9 mg/L, while the filtered water indicated an average of 23±3.7 mg/L. Such conditions usually implicate moderate levels of species diversity as well as the absence of nuisance growth of aquatic plants and blue-green algae [21].

3.4.8 Manganese

Manganese is a grey-white, brittle metal and relatively abundant on earth constituting making up approximately 0.1% of the earth's crust. This element is an essential plant nutrient and appears to be required as an enzyme activator. The DWAF found that the manganese concentrations are highest in the reproductive sections (seeds) of the plants and lowest in the woody parts [18].

The respective average manganese concentrations obtained in the unfiltered and filtered water were 7.5±0.6 mg/L and 0.11±0.01 mg/L. Irrigation standards provided by DWAF indicated that manganese concentrations in the range of 0.02-10.0 mg/L is the maximum allowable concentrations for fine-textured neutral to alkaline soils, however the target range is 0-0.02 mg/L [19]. Thus both unfiltered and filtered water is above the target range, although the filtered levels are only marginally higher.

The target range relating to industrial use is between 0 and 0.05 mg/L [22]. Manganese concentrations present in the unfiltered water are well above the target levels and may cause damage due to precipitation of manganese compounds. Filtered water on the other hand showed levels much lower causing only moderate damage as a result of precipitation.

Standards regarding domestic use require a target range of 0-0.05 mg/L. Unfiltered water may have severe aesthetical effects although health effects are rare whereas filtered water in the threshold for significant staining and taste problems [18].

3.5 Summary

Tables II & III are representations of the applicability of all the parameters investigated in this chapter.

Table II: Applicability of unfiltered water (I-Industrial use, D-Domestic use, A-Agricultural use).

Parameter	Value	Target range	Application
TDS (mg/L)	8940±795	3000	-
Total Hardness (mg/L)	130±5.44	300	I, D, A
SAR	0.36±0.01	15	I, D, A
Potassium (mg/L)	376±8.5	400	I, D, A
Sodium (mg/L)	12.8±0.61	5000	I, D, A
Phosphorus (g/L)	104±6	250000	I, D, A
Manganese (mg/L)	7.5±0.6	20	I, A

Table III: Applicability of filtered water (I-Industrial use, D-Domestic use, A-Agricultural use).

Parameter	Value	Limit	Application
TDS (mg/L)	8940±795	3000	-
Total Hardness (mg/L)	2.4±0.061	300	I, D, A
SAR	15.7±1.04	15	I, D, A
Potassium(mg/L)	96±9.5	400	I, D, A
Sodium (mg/L)	9.2±0.4	5000	I, D, A
Phosphorus (g/L)	23±4	250000	I, D, A
Manganese (mg/L)	0.11±0.01	20	I, A

If no regulations were provided by the DWAF regarding the applicability of the parameters investigated in this study, it was assumed that such parameters are applicable. The limits provided in Tables II & III were taken as the highest posssible limit provided by the DWAF regarding domestic, industrial and agricultural applicability. Although the water may be applicable in most of the cases presented in Tables II & III, it may not be without effects and it is recommended to complete furhter purification steps for safe domestic use.

4 CONCLUSIONS

In this study Celluclast, Pectinex Ultra SP-L and Tween 80 were utilized in a process to chemically extract water from pulp retrieved from water hyacinth. The objective of this study was to determine the optimal process conditions for the water extraction process in order to obtain the largest yield. To determine the optimal process conditions, all three chemicals added had to be investigated as each had its distinctive set of optimum conditions.

The water yield served as the most significant factor in determining the optimal conditions, however, the water quality was also to be considered in order to determine the applications thereof. It was found that experiments conducted by using water hyacinth pulp with a stems to leaves ratio of 9:1 increased the average water yield with 10-15 wt% in comparison to pulp with a ratio of 1:1, utilized at identical process conditions.

The average yields obtained for Celluclast, Pectinex Ultra SP-L and Tween 80 without the addition of water during the preparation phase of the experiments were 70.8±4.88, 69.5±7.2 and 66.9±6.46 wt% respectively. Experiments that included the addition of 140 ml of water generated up to 15% higher yield in comparison to those excluding additional water. Thus the respective, average yields for Celluclast, Pectinex Ultra SP-L and Tween 80 were 82.8±5, 85.82±3.4 and 80±1.8 wt% for the experiments containing an additional 140 ml of water. The average yield obtained for a mixture of Celluclast and Pectinex Ultra SP-L without the addition of water was 80±2.5 wt% while an average yield of 86.8±3.16 wt% was obtained for experiments including additional water. An average yield of 86±1.26 wt% was achieved in the event of employing 140 ml of recycled water.

The largest yield (88±3 wt%/wt) was obtained in combining a mixture of the two enzymes (Celluclast and Pectinex Ultra SP-L) with an additional 140 ml of water at a pH of 4 and temperature of 37.5 °C. During this study it was concluded that combining Celluclast and Pectinex Ultra SP-L produced the highest average water yield, while Tween 80 proved to be feeble in comparison to the two enzymes. Both Celluclast and Pectinex Ultra SP-L generated high percentage yields with Pectinex Ultra SP-L proving to be the better extraction agent by a small margin.

In conclusion it was found that the addition of extra water during the preparation phase prior to placing the samples in the oven increased the average water yield with approximately 5-10 %. Further studies on the addition of water will have to be conducted to establish the economic feasibility of the addition of water.

Analysis conducted to verify the quality of the extracted water concluded that it may well be used for agricultural and industrial purposes, however, not for domestic use. Due to the concentration levels of the parameters included in Tables II & III overshooting the target quality ranges for water, provided by the DWAF, negative impacts may persist and result in various dilemmas such as damage to equipment and interference with industrial processes.

From the analysis conducted by the Envirocare Laboratory in is clear that the implementation of activated carbon- and sediment filters had a reducing effect on most of the elements analyzed, however, not on the levels of the total dissolved solids (TDS) present in the water.

Further applications that have not yet been thoroughly investigated include the utilization of the biomass obtained as a possible food supplement for farm animals and the production of biogas.

Should any further studies persist, it is recommended to investigate the economic feasibility of both the extraction process as well as the purification of the extracted water to different levels.

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