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Recovery of water from cacti for use in small farming communities

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In this study, an extensive investigation was conducted to determine if declared weeds could be used as a source of water for agricultural practices in dry areas. The objective of this study was to determine if declared weeds could successfully be used as a source of water for agricultural practices in dry areas by extracting the water by means of mechanical and chemical methods. The *Cereus jamacura* cactus, also known as Queen of the Night, with a moisture content of 91 wt%, was selected for this study. Both mechanical and chemical extraction methods were used to determine the maximum water yield possible. Juicing, pressing with a hydraulic cold press and pressing with rollers were used as mechanical methods to extract water from the cacti and water yields of 7.0, 4.9 and 2.9 wt% were obtained respectively. The chemical extraction processes entailed the pulping of the cacti and the filtering off of the water. The effect of pectinase, cellulase and a surfactant at a fixed dosage on the amount of water extracted (mass of water per mass of cacti used) was investigated. The quality of the water was also determined. Temperature (30 to 50°C) and pH (2.5 to 6.5) were varied to find the optimum extraction conditions. The highest water yield (55 wt% of total cacti mass) was obtained using pectinase enzymes at a temperature of 40°C and a pH of 3.5 and cellulose enzymes at a temperature of 35°C and a pH of 5.5. This relates to a yield of 550 L of water per ton of cacti, making chemical water extraction a viable option if compared to the pollution created by the annual burning of the cacti. It was concluded from this study that the water that was extracted from the *C. jamacaru* cacti would not be suitable for either domestic or industrial application due to the high levels of potassium (up to 2,650 ppm), phosphates (up to 2,200 ppm), sulphates (up to 3,800 ppm) and nitrates (up to 670 ppm) in the water. The high concentration of phosphates and nitrates, however, makes the extracted water an excellent fertiliser for crops requiring high nitrate and phosphate dosages. Small community farmers could thus benefit by using cacti as a source of water for small scale biofuels production plants while also obtaining an excellent additional fertiliser for crop cultivation.

Key words: *Cereus jamacaru*, water yield, water quality.

INTRODUCTION

The availability of water for domestic, industrial and agricultural application is a growing worldwide concern, with an increasing number of areas being chronically short of water (UNESCO, 2012). Climate change, drought and desertification have impacted large parts of the Southern African region, especially areas where people are primarily dependant on natural resources (Dougilla et al., 2009). As the 30th driest country in the world, with an

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average rainfall of just 450 mm per annum, South Africa faces the same water scarcity problem as the rest of the world (DEA, 2011). Exploring available water sources in arid areas that are not yet being utilised is thus of utmost importance.

Cacti are succulent plants due to their ability to store water in their tissues. The efficient storage of water in the cacti's stem, body, leaves and roots, as well as the plant's low water consumption, allow cacti to resist extreme desert conditions (Andreote et al., 2013). Certain South African cacti species, like *Cereus jamacura*, *Opuntia ficus-indica*, *Opuntia imbricata* and *Echinopsis spachiana*, are further classified as invasive plants and declared as category 1 weeds according to the South African Conservation of Agricultural Resources Act (43 of 1983). These cacti species are targeted for control due to their serious environmental impact, including higher usage of water, blockage of water passages, erosion, as well as the reduction in the specific environment's biodiversity.

The Thusanang area, situated in South Africa's North-West province, is a very dry region where declared cacti species grow abundantly. Currently both farmers and members of the rural community merely cut down these cacti, dry the leaves and use the dried leaves as fuel for cooking and heating purposes. Not only is the valuable water not recovered from the cacti, but the burning of this plant material increases greenhouse gas emissions.

In previous studies by Costa et al. (2012), Degu et al. (2009) and Gebremariam et al. (2006) cacti were shown to be successfully used as an animal feed supplement. The objective of this study is to determine whether water can be effectively extracted from the cacti using mechanical and chemical extraction processes and whether the extracted water can be utilised for domestic, industrial or agricultural purposes. The focus is placed on *Cereus jamacura*, which is found in the Thusanang area. *Cereus jamacura* is often used as a cattle fence by South African farmers. In studies by Díaz-Medina et al. (2012) and De Albuquerque et al. (2008) the potential of the cactus's medical application was indicated.

Mechanical methods used for recovering juice from fruit include chopping, pressing, diffusion and centrifugal processes. The purpose of these methods is to separate the liquid phase from the solid phase (Hui et al., 2002). It is proposed to use juicing, pressing with a hydraulic cold press and pressing with rollers as mechanical methods to extract water from the cacti. The three processes were selected based on the simplicity, low maintenance and low capital input required.

Juicing using a juicer or an extractor produces a murky liquid product that contains no suspended solids (Barrett et al., 2004). Juicing by rotary methods increases the amount of polysaccharides (including pectin and cellulose) extracted from the pulp to the liquid product (Hui et al., 2002).

The hydraulic cold press is used in small juicing companies and was the only fruit juicing method for many years (Barrett et al., 2004). Roller presses work by pushing two cylinders or rollers against each other and sending fruit pieces between the two rollers while the rollers are turning (Tzia and Laidakis, 2003). The resulting liquid products of both the hydraulic cold press and the roller press are clearer than the liquid product obtained by rotary methods (Hui et al., 2002).

Chemical extraction techniques, on the other hand, are also well documented in literature and readily available. The combined synergetic use of pectinase and cellulase further increases the extraction yield of the juice (Abbès et al., 2011). In a study by Sreenath et al. (1994) the addition of cellulose and pectinase increased the recovery of juice from pineapples by up to 14%. Demir et al. (2001) did a similar study and found that pectinase increased juice yield from carrots by 17.7%. Furthermore, surfactants also play an important role in breaking down cellulose in plants and fruit. In a study by Yang et al. (2011) it was shown that a surfactant can increase the hydrolysis of cellulose at high rotation speeds.

Based on these successful applications of cellulase, pectinase and surfactants, it is proposed to improve water extraction from the pulped cacti by using these extraction agents. Cellulase and pectinase are both enzymes which are generally used in food processes where juice is extracted. Each enzyme is known for its ability to break down specific components in the structures of fruit and was therefore suitable for the specific study. The surfactant, on the other hand, is a known polysorbate which is used in a variety of industries, including healthcare and detergents.

MATERIALS AND METHODS

C. jamacura cacti were collected from the Thusanang rural community. The cacti pieces used were the leaves chopped off from the full-grown plants. Celluclast 1.5 L (Novozymes) with a cellulose content of 15 wt% and Pectinex Ultra SP-L (Novozymes) with a polygalacturonase content of 5 wt% were used as enzymes. Tween 80 (Merck), with a saponification number of 45 to 55 mg KOH/g and a hydroxyl number of 65 to 80 mg/g, was used as surfactant. NaOH (98%, Labchem) and H_2SO_4 (98%, Labchem) were used to adjust pH. All chemicals were used without further purification.

Moisture content

The moisture content of the cacti was determined by baking the chopped leaves in baking pans in an oven at 105°C for 24 h. The dry mass was subtracted from the wet mass to determine the moisture content.

Mechanical extraction of water

A Russell Hobbs Juice Sensation juicer was used for the juicing of the cacti and the extracted juice's weight recorded. A custom-built hydraulic cold press (Figure 1) was used for pressing the cacti cladodes. The cacti cladodes were cut into chunks to fit into the 8.5 cm diameter cylinder of the cold press. The water was collected in

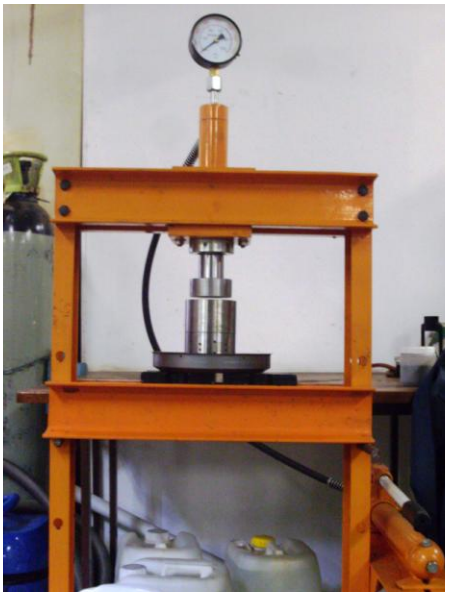

Figure 1. Custom-built hydraulic cold press.

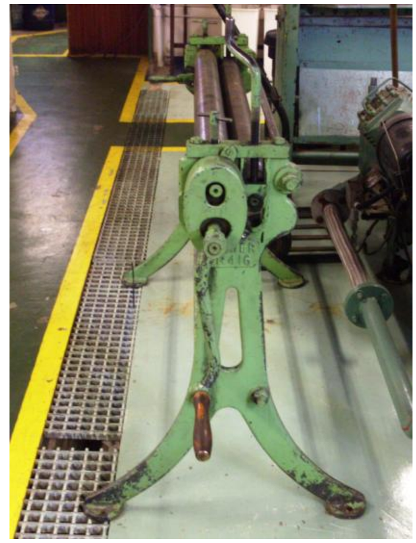

Figure 2. Custom-built roller press.

Figure 3. Chopped cactus leaves without thorns or bad spots.

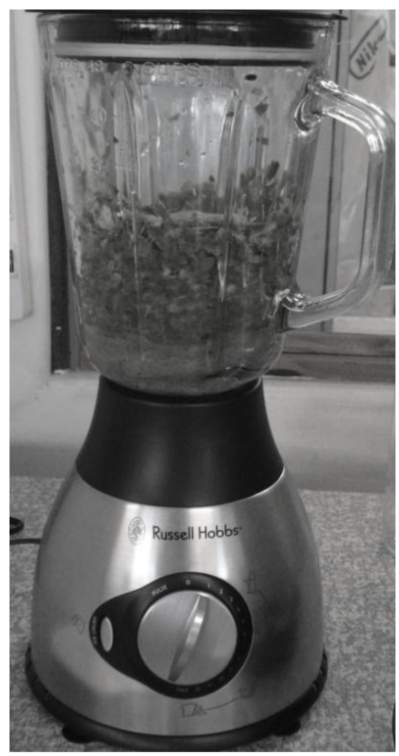

Figure 4. Juicing the chopped cactus leaves using a Russell Hobbes juicer.

the collector ring and the weight of the extracted water recorded. A custom-built roller press (Figure 2) was used for roll pressing of the cacti. A glass beaker was placed underneath the rollers to collect the extracted water.

Chemical extraction of water

The experimental procedure consisted of two stages. The first stage entailed the juicing of the cactus leaves. First of all, the thorns and bad spots were removed from the leaves. The leaves were then chopped into smaller pieces, as shown in Figure 3. For the juicing step, a Russell Hobbs juicer was filled with small cactus pieces (Figure 4) to produce a pulp medium, as shown in Figure 5.

The second stage entailed the extraction of the water from the cactus pulp. The experimental extraction method for all three

Figure 5. Cactus pulp.

extraction agents (Celluclast 1.5L, Pectinex Ultra SP-L and Tween 80) is identical. Initially, a Duran flask (1000 ml) was filled with 200 g of cacti pulp. A Scientific Series 2000 oven was used to accurately maintain the predetermined temperature during the experiment. The pH was adjusted throughout using NaOH and H_2SO_4.

The optimum extraction conditions were determined by investigating the influence of temperature and pH on the extraction of water from the cacti pulp. All experiments were executed at a constant extraction agent dosage of 14 g for the enzymatic experiments (0.07 wt/wt% for both the Celluclast 1.5L and Pectinex Ultra SP-L) and 0.25 g for the surfactant experiments (1.25 g/kg for the Tween 80).

The pH dependant experiments were executed at a constant temperature of 40°C. The pH was controlled at five specific values, ranging from 2.5 to 6.5. All of the temperature dependant experiments were carried out at a constant pH of 4.5. The temperature was controlled at five specific values, ranging from 30 to 50°C.

The duration of the experiments included an oven time of an hour at the specific temperature and pH. Afterwards the oven temperature was increased to 99°C for 20 min to ensure that the enzymes undergo a process of denaturation. After a cooling period, the water and solid pieces were separated by means of a Büchner filter. A compositional analysis was done on a sample of the filtered water. For the determination of the total dissolved solids (TDS), micro-filtration was performed using 0.22 µm filters.

RESULTS AND DISCUSSION

Moisture content

Most cacti consist of about 90 wt% water (Stuart, 2009). The moisture content of *C. jamacura* was found to be 90.9 wt% (± 1.28 wt%). The high moisture content is comparable with studies on other cacti species. Gebremarium et al. (2006) found *Opuntia ficus-indica* to have a moisture content of 88.0 wt%.

Mechanical extraction

Poor water yields were obtained by means of mechanical extraction. Juicing yielded 7.0 wt% water, while 4.9 and 2.9 wt% were obtained with the hydraulic cold press and the rollers respectively. The juicer has the highest water yield of the three mechanical extraction methods, even though the liquid product is very thick and slimy. The water extracted with the cold press was a clear liquid, due to the lower cellulose and mucilage polysaccharides (Hui et al., 2002). The very low yield obtained by means of the rollers can be explained by insufficient pressure exerted on the cactus cladodes.

Chemical extraction

The effect of pH

The pH affects the water yield for both the enzymes and the surfactant. In Table 1 it can be seen that in the case of Celluclast 1.5 L, the water yield increased as the pH increased and decreased again beyond the optimum pH of 5.5. The maximum water yield of 55 (± 13.3 wt%) was obtained at a pH of 5.5. The water yield remained constant over the pH range in the case of Pectinex Ultra SP-L, with a maximum yield of 55 (± 22.6 wt%) at a pH of 3.5. Tween 80 shows an opposite trend if compared to that of Celluclast 1.5 L. With an increase in pH, the water yield decreased. The maximum water yield with Tween 80 of 50 (± 9.3 wt%) is obtained at a pH of 3.5.

The temperature also affects the water yield for both the enzymes and the surfactant. In Table 2, it can be seen that the maximum water yield of 55 (± 33 wt%) and 50 (± 24 wt%) was obtained for Celluclast 1.5 L and Tween 80, respectively at a temperature of 35°C. In the case of Pectinex Ultra SP-L, a maximum yield of 51 (± 31.1 wt%) was obtained at 40°C.

Water quality

The quality of the extracted water was analysed to determine whether the water would be suitable for domestic, industrial or agricultural use. The concentration of specific constituents, the total dissolved solids (TDS),

Table 1. Effect of pH on the water extraction yield.

pH	Celluclast 1.5 L	Pectinex Ultra SP-L	Tween 80
2.5	39	50	48
3.5	50	55	50
4.5	51	49	41
5.5	55	53	45
6.5	51	54	44

Table 2. Effect of temperature on the water extraction yield.

Temperature (ºC)	Celluclast 1.5 L	Pectinex Ultra SP-L	Tween 80
30	36	35	45
35	55	49	50
40	46	51	46
45	40	43	42
50	40	50	39

Table 3. Chemical analyses of extracted water.

Parameter	Celluclast 1.5 L	Pectinex ultra SP-L	Tween 80	Domestic standard	Industrial standard	Agricultural standard
TDS (mg/L)	12,239	11,039	11,639	< 450	< 1600	<10,000
Total hardness (mg/L)	2,073	2,278	2,184	< 100	< 1000	Not available
Ca (mg/L)	1,407	1,572	1,559	< 32	Not given	Not given
Mg (mg/L)	666	706	625	< 30	Not given	Not given
Sodium adsorption Ratio	0.04	0.02	0.02	Not given	Not given	< 2.00
Na (mg/L)	34	14	12	< 100	Not given	Not given
K (mg/L)	2,643	2,221	2,483	< 50	Not given	Not given
PO_4 (mg/L)	2,128	1,067	689	Not given	Not given	Not given
SO_4 (mg/L)	3,827	3,709	1,896	< 200	< 500	Not given
NO_3 (mg/L)	402	667	14	< 6	Not given	< 10
NO_2 (mg/L)	0	0	0	< 6	Not given	Not given

the total hardness of the water, as well as the sodium adsorption ratio, are given in Table 3. The water quality corresponds to the water extracted at the optimum pH and temperature for each one of the extraction agents.

The total dissolved solids (TDS) refer to the amount of inorganic salts dissolved in the water. The TDS levels for all the samples are well above the target ranges, making it unsuitable for domestic, industrial and agricultural uses (DWAF, 1996). However, there are commercial crops that reveal higher salt tolerance. These include amongst others asparagus, barley, cotton, rye, sugar beet and wheat (Maas and Kotze, 1990).

The total hardness of water can be defined as the sum of the magnesium and calcium concentrations present in the water. The total hardness levels of the extracted water of all the samples were well above the assigned target ranges for both domestic and industrial use (DWAF, 1996). As no guidelines are provided for agricultural application, it may prove to be beneficial when used for specialised irrigation applications for crops with a deficiency in calcium and magnesium.

The sodium adsorption rate (SAR) serves as an indication of the potential of water to induce sodic soil conditions. It also illustrates the level at which the soil's exchangeable sodium percentage (ESP) will stabilize after a long period of irrigation. This is only considered for the agricultural application of the water for irrigation purposes. The SAR is calculated using the measured concentrations of sodium, calcium and magnesium. The SAR remains well below 2 for all the samples. The extracted water can therefore be used for irrigation.

There is a further guideline with regards to the sodium level in the water. In all three samples the sodium level meets the requirement for domestic use. Potassium plays a prominent role in plant growth. Potassium nitrate and various other potassium compounds are quite often used as fertilisers. Guidelines for potassium are only provided for domestic use. The concentration of potassium is well above the desired level, making the water unsuitable for domestic use. However, potassium-rich water will be suitable for agricultural irrigation purposes.

No guidelines are provided by the Department of Water Affairs and Forestry for the concentration of phosphates in water (DWAF, 1996). Plants do have a phosphorous need which has to be satisfied and this result in the use of fertilizers containing phosphorous. The possibility of using the water for agricultural irrigation purposes is therefore attractive.

The concentrations of sulphates present in the water are well above the given ranges for both household and industrial uses (DWAF, 1996). However, sulphates are a good source of sulphur, which is required by plants for growth. The use of fertilizers containing sulphur is used to increase the yields of crops and to reduce the necessity of sulphur leaching (Scherer, 2001).

The concentration of nitrates and nitrites is limited in water for domestic use due to the impact it may have on human health (DWAF, 1996). Target ranges for the application of agricultural irrigation exist and the presence has an effect on the quality and yields of crops (DWAF, 1996). None of the extraction agents was able to successfully reduce the nitrates level below 10 mg/L, but Tween 80 managed to reduce the nitrates level to 14 mg/L, which is much lower than the 402 mg/L and 667 mg/L of the Celluclast 1.5 and Pectinex Ultra SP-L.

Conclusions

In the study, mechanical and chemical extraction methods were used to determine the highest water yield possible from cacti. Mechanical methods proved to be unsuccessful and a maximum yield of 7 wt% was obtained by using a juicer.

Chemical extraction methods proved to be more efficient. Celluclast, Pectinex Ultra SP-L and Tween 80 were added to cacti pulp at different process conditions. The optimum process conditions for the highest water yield were obtained as follows:

i. Celluclast 1.5L:55 wt% (T = 40ºC and pH = 5.5)

ii. Pectinex Ultra SP-L:55 wt% (T = 40ºC and pH = 3.5)

iii. Tween 80:50 wt% (T = 40ºC and pH = 3.5)

The quality of the water was evaluated with regards to the concentration of the major constituents. It can be concluded that the extracted water is not suitable for domestic or industrial application. The water is, however, suitable for agricultural use without further treatment with regards to the total hardness, the sodium adsorption ratio, potassium, phosphates and sulphates.

The extracted water has a total dissolved solids content higher that specified for agricultural application. The extracted water will either need to be filtered additionally or only used for higher salt tolerant crops. Nitrates are the only other concern with regards to agricultural application and will require additional treatment to counter a possible decrease in the quality and yield of crops, especially in the water extracted using Celluclast 1.5L and Pectinex Ultra SP-L.

It can thus be concluded that the extracted water is suitable for specialised agricultural irrigation purposes.

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