Physicochemical Characterization of Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms)

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Water hyacinth (*Eichhornia crassipes*) is an aquatic flowering plant that belongs to the Pontederiaceae family. The plant is a freshwater hydrophyte that grows in subtropical and tropical regions of the world. The objective of this study was to determine the physicochemical characterization of roots, stems, and leaves of *E. crassipes*. The pH, ash, 1% alkali solubility, extractives, lignin, holocellulose, tannins, and calorific value were determined. Our results showed that the mineral content is relatively high, whereas that for lignin and tannins is low. The pH is moderately acid, and the soluble substances easily dissolved in alkali or organic solvents. Potassium, calcium, and silicon are the major constituents present in the ash of this plant. The determined calorific value was approximately 14.4 MJ/kg.

Keywords: pH; Ash; Extractives; Lignocellulosic material; Calorific value

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INTRODUCTION

The water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is an aquatic flowering plant that belongs to the Pontederiaceae family. The plant is a freshwater hydrophyte that grows in subtropical and tropical regions of the world. Sometimes the water hyacinth is considered an undesirable weed; but various studies have reported its uses, such as in the production of ethanol (Manivannan *et al*. 2012; Awasthi *et al*. 2013; Fileto-Pérez *et al*. 2013; Manivannan and Narendhirakannan 2014); as an adsorbent for heavy metals present in polluted water (Murithi *et al*. 2014); for phytoremediation (Vijetha *et al*. 2014); as a raw material for the production of biogas (Ochieng and Kaseje 2014); as a biofuel (Bergier *et al*. 2012); and as a protein supplement in ruminant feed (Mako *et al*. 2011). Other works have focused on the effect of extractives on its antimicrobial activity (Tharamaiselvi and Jayanathi 2012), or its potential to provide phytosterols for the pharmaceutical industry (Fileto-Pérez *et al*. 2015). The objective of this study was to determine the physicochemical characterization of roots, stems, and leaves of *E. crassipes* with the aim of providing a basis for future applications.

EXPERIMENTAL

Materials

Water hyacinth plants were collected from two different regions: El Tunal River (TR), located in Durango, Durango, México (26°48´-22°19´ Latitude, 102°28´-107°11´ Longitude), at 1880 meters above sea level (masl) and from Yuriria Lake (YL) located in Yuriria, Guanajuato, Mexico (20°14´24.07" Latitude, 101°07´12.98" Longitude), at 1737 masl. The plants were washed; roots, stems, and leaves are separated, and dried under shade. The material was then milled and sieved. The plant portions smaller than 420 µm were used in our study. Moisture content was determined by exposing the material at 105 ± 3 °C according to the TAPPI T264 cm-97 method (2000a). All tests were repeated six times. Mean values and standard deviation are reported.

Chemical Properties

The pH (Sandermann and Rothkamm 1959), ash content (TAPPI T211 om-93 2000b), ash microanalysis (Tellez *et al*. 2010), 1% alkali solubility (TAPPI T212 om-98 2000c), and extractives of the dry raw material were determined. The total extractives content was determined by successive Soxhlet extractions using various organic solvents (cyclohexane, acetone, and methanol) and finally hot water under reflux. For this purpose each case was refluxed for 6 h. A rotary evaporator under vacuum was used for solvent recovery. Lignin, holocellulose, and cellulose in the extractive-free material were determined following the procedures reported by Runkel and Wilke (1951); Wise *et al*. (1946); and ASTM D1103-60 (1981), respectively. Hemicellulose content was determined by the difference between holocellulose and cellulose (Carballo-Abreu *et al*. 2004).

Tannins Content

The total extract, tannin content, and Stiasny number in the dry material were determined accordingly to Yazaki and Hillis (1977) and Waterman and Mole (1994), using water and ethanol as solvents.

Calorific Value

The calorific values of the sections of the water hyacinth were determined using a colorimetric pump (Parr Model 6772, USA). For this purpose, 0.5 g of dried roots, stems, and leaves, as original material, was pressed to form pellets in a laboratory press (Carver model 4350-L) at 1,000 kg/cm^2 that were then placed into the instrument. The measurements were performed following the UNE-EN 14918 (2011) procedure. The calorific value was also determined in the extractives-free material, lignin, and holocellulose in the same process as the original material.

RESULTS AND DISCUSSION

Chemical Properties

The basic characterization of *E. crassipes* is summarized in Table 1. The pH of all portions of the plant was similar and equal to 4.6. The mineral content of the studied plants ranged from 12.4 to 26.8 wt.%, with the samples collected from TR providing higher inorganic substances than the samples obtained from YL. This may be due to the water quality at the respective locations. The results reported for the same species by others are

of the same magnitude: 21.5% by Mako *et al*. (2011), 17% in leaves (Saha and Ray 2011), 19% by Promdee *et al*. (2012), 22.9% by Fileto-Pérez *et al*. (2013), and 12.4% in leaves by Sotolu (2012).

Table 2 shows the microanalysis of ash. The major elements were silicon, calcium, and potassium. High concentrations of potassium, chlorine, and calcium were detected in stems, whereas potassium and calcium were the major elements present in leaves. It is interesting to note that iron was only found in roots and stems. Most chemical elements found here have been reported previously for this species (Mako *et al*. 2011; Sotolu 2012). It is important to note that heavy metals were not found in the studied samples. The high concentration of inorganic substances (Table 2) makes this plant attractive to use as compost because minerals are important for plant growth (Restrepo and Pinheiro 2009).

Table 1. Characterization of *E. crassipes* from TR and YL

Analysis	Collecting site	Plant part		
		Root	Stems	Leaves
pH	TR	4.6 ± 0.01	4.7 ± 0.04	4.7 ± 0.14
	YL	4.6 ± 0.02	4.7 ± 0.06	4.7 ± 0.01
Ash (wt %)	TR	26.0 ± 0.22	26.8 ± 0.39	19.9 ± 0.25
	YL	14.6 ± 0.09	14.4 ± 0.03	12.4 ± 0.04
Alkali solubility (wt %)	TR	54.4 ± 0.21	52.4 ± 0.34	51.8 ± 0.27
	YL	55.9 ± 0.23	48.9 ± 0.19	51.2 ± 0.23
Total extractives (wt %)	TR	35.9 ± 0.82	58.0 ± 0.78	47.5 ± 0.12
	YL	30.4 ± 0.42	31.9 ± 0.31	29.5 ± 0.02
Runkel lignin (wt %)	TR	13.4 ± 0.53	4.5 ± 0.08	11.5 ± 0.91
	YL	8.8 ± 0.17	5.9 ± 0.18	14.3 ± 0.27
Holocellulose (wt %)	TR	23.7 ± 0.45	11.4 ± 0.50	17.1 ± 0.06
	YL	43.4 ± 0.04	40.0 ± 0.34	36.8 ± 0.35
Cellulose (wt %)	TR	16.0 ± 0.77	8.4 ± 0.21	8.7 ± 0.76
	YL	15.9 ± 0.45	14.2 ± 0.57	12.8 ± 0.30
Hemicellulose* (wt %)	TR	7.7	3.0	8.4
	YL	27.5	25.8	24.0

*Hemicellulose content was calculated by the difference between holocellulose and cellulose.

Alkali solubility ranged from 48.9 to 55.9 wt.%, which is higher than those reported for wood species (Bernabé-Santiago *et al*. 2013). It is known that hot alkali solution extracts low-molecular-weight carbohydrates consisting mainly of hemicellulose and degraded cellulose and this treatment can influence the natural durability of lignocellulosic materials (TAPPI T212 om-98 2000). On the other hand, it is expected that water hyacinth could be easily damaged by the action of microorganisms, because this plant has high alkali solubility.

The total extractives content ranged from 29.5 to 58.0 wt.%, in agreement with or higher than other values reported for tropical wood species (Rutiaga *et al*. 2010; Téllez *et al*. 2010; Ramos-Pantaleón *et al*. 2011). The total solubility of *E. crassipes* samples was obtained by a sequential extraction with cyclohexane, acetone, methanol, and hot water (Table 3). The lowest extractives content (0.08 wt.%) was observed in roots using cyclohexane, and the highest extractives content (35.3 wt.%) was in stems using hot water. In general, the highest amount of extractives in *E. crassipes* was observed using methanol and hot water as solvents, which confirms the high polyphenol content in these samples. Lipophilic compounds were relatively abundant in our samples, except in the roots, which had the lowest value (0.8 wt.%). The high content of extractives in *E. crassipes* can have a

negative impact if the plant is used as raw material for pulping processes because extractives increase chemical consumption. However, *E. crassipes* is an attractive chemical source of derivatives that remains to be explored.

The Runkel lignin content ranged from 5.9% to 14.3% (Table 1), similar to other values reported for the same species: 3.5% by Kumar *et al*. (2009), 17% by Abdel-Fattah and Abdel-Naby (2012), and 3.9% by Reales-Alfaro *et al*. (2013). The low lignin content in *E. crassipes* makes this material attractive for the production of ethanol, as previously suggested (Satyanagalakshmi *et al*. 2011; Abdel-Fattah and Abdel-Naby 2012; Ganguly *et al*. 2012; Awasthi *et al*. 2013; Fileto-Pérez *et al*. 2013; Reales-Alfaro *et al*. 2013).

Table 2. Elemental Microanalysis of the Ash of *E. crassipes* (Atomic %), Determined by EDS

Elements	Collecting site	Plant section		
		Roots	Stems	Leaves
Sodium	TR	0.67 ± 0.06	4.43 ± 0.60	1.51 ± 0.33
	YL	5.58 ± 0.16	2.01 ± 0.37	0.68 ± 0.32
Magnesium	TR	0.46 ± 0.05	5.33 ± 0.02	3.76 ± 0.59
	YL	16.37 ± 0.43	6.00 ± 0.32	7.39 ± 0.66
Aluminum	TR	8.84 ± 0.53	0.82 ± 0.07	0.03 ± 0.01
	YL	0.25 ± 0.01	0.27 ± 0.01	0.21 ± 0.01
Silicon	TR	62.80 ± 0.06	8.06 ± 0.03	2.21 ± 0.03
	YL	1.61 ± 0.07	1.97 ± 0.70	2.23 ± 0.03
Phosphorus	TR	1.81 ± 0.01	5.12 ± 0.06	8.61 ± 0.04
	YL	5.99 ± 0.25	4.64 ± 0.40	5.87 ± 0.73
Sulfur	TR	1.07 ± 0.09	2.44 ± 0.03	2.76 ± 0.02
	YL	5.91 ± 0.21	0.37 ± 0.01	0.44 ± 0.03
Chlorine	TR	0.71 ± 0.01	19.43 ± 0.33	17.44 ± 0.12
	YL	12.20 ± 0.25	21.47 ± 0.28	15.93 ± 0.57
Potassium	TR	10.92 ± 0.03	38.36 ± 0.03	47.29 ± 0.30
	YL	21.79 ± 0.17	41.49 ± 0.55	42.11 ± 0.23
Calcium	TR	5.30 ± 0.00	15.05 ± 0.05	16.11 ± 0.08
	YL	28.92 ± 0.59	20.27 ± 0.79	23.98 ± 0.63
Manganese	TR	1.96 ± 0.03	0.70 ± 0.06	0.28 ± 0.02
	YL	1.16 ± 0.04	1.31 ± 0.03	1.16 ± 0.02
Iron	TR	5.45 ± 0.07	0.26 ± 0.01	nd
	YL	0.21 ± 0.07	0.20 ± 0.05	nd

nd = not detected

Regarding polysaccharides in the water hyacinth samples, the holocellulose content ranged from 11.4 to 43.3 wt.% (Table 1). The lowest content of cellulose (8.4 wt.%) was observed in stems, and the highest (16.0%) was found in roots. The values found here were low compared to other reports, for example, 18.2% by Kumar *et al*. (2009), and 18.2% by Fileto-Pérez *et al*. (2013). The hemicellulose content in our samples ranged from 3 to 27.5 wt. %, which is smaller than the values reported in other studies for the same species: 48.7% (Kumar *et al*. 2009) and 49.3% (Fileto-Pérez *et al*. 2013). If *E. crassipes* were used as a raw material in the pulping process, the pulp yield would be low because of the lower polysaccharide content found in this plant.

Tannins Content

The evaluation of tannins in *E. crassipes* is summarized in Table 4. The values for total extract (TE) ranged from 12.1 in roots to 15.7 wt.% in leaves, using ethanol and water

as solvents, respectively. These values are slightly higher than those reported for the barks of some pine species (Rosales and González 2003) and in the range for those reported for barks of other hardwood species: 11.1 wt.% for *Erythroxylon compactum* and 17.7 wt.% for *Senna skinneri* (Colín-Urieta *et al*. 2013).

The Stiasny number (SN) in leaves ranged from 41.5% to 52.8% by aqueous and ethanolic extraction, respectively. These values are similar to others reported for pine barks (30 to 80 wt. %) (Rosales and González 2003) and lower than those published by Colín-Urieta *et al*. (2013), who found 60.1 wt.% for *Erythroxylon compactum* and 79.4 wt.% for *Senna skinneri*.

Table 3. Results of Successive Soxhlet Extraction using Various Solvents (wt.%)

Samples	Collecting site	Solvent				
		Cyclohexane	Acetone	Methanol	Hot water	Total
Roots	TR	0.8 ± 0.06	1.6 ± 0.06	4.9 ± 0.19	31.6 ± 0.68	35.9 ± 0.82
	YL	0.8 ± 0.01	2.2 ± 0.02	13.3 ± 0.31	14.1 ± 0.14	30.4 ± 0.42
Stems	TR	3.4 ± 0.34	4.2 ± 0.42	15.1 ± 0.79	35.3 ± 0.10	58.1 ± 0.78
	YL	1.4 ± 0.01	2.6 ± 0.05	18.8 ± 0.04	9.1 ± 0.41	31.9 ± 0.31
Leaves	TR	6.9 ± 0.37	5.6 ± 0.25	15.2 ± 0.67	19.9 ± 0.41	47.5 ± 0.12
	YL	2.4 ± 0.01	2.2 ± 0.02	12.6 ± 0.02	12.3 ± 0.07	29.5 ± 0.02

Table 4. Tannins in Roots, Stems, and Leaves from *E. crassipes* (wt. %)

Samples	Collecting site	Aqueous extraction			Ethanolic extraction		
		TE	SN	T	TE	SN	T
Roots	TR	14.3 ± 0.07	46.3 ± 0.11	6.5 ± 0.10	13.5 ± 0.01	51.3 ± 0.13	6.9 ± 0.10
	YL	13.3 ± 0.08	44.8 ± 0.01	6.0 ± 0.06	12.1 ± 0.07	51.2 ± 0.07	6.2 ± 0.06
Stems	TR	13.8 ± 0.05	43.8 ± 0.21	6.0 ± 0.32	14.9 ± 0.07	47.4 ± 0.07	6.7 ± 0.21
	YL	12.7 ± 0.28	42.6 ± 0.04	5.4 ± 0.12	13.9 ± 0.07	46.4 ± 0.07	6.4 ± 0.06
Leaves	TR	15.7 ± 0.17	41.5 ± 0.05	6.4 ± 0.08	13.1 ± 0.07	52.4 ± 0.07	6.9 ± 0.05
	YL	14.4 ± 0.02	40.8 ± 0.00	5.9 ± 0.01	12.9 ± 0.07	52.8 ± 0.07	6.8 ± 0.01

The amount of condensed tannins (T) in roots and leaves in our study ranged from 5.4 by aqueous to 6.9 wt.% by ethanolic extraction. This content is higher compared to that reported for leaves (0.98%) in *E. crassipes* (Saha and Ray 2011) or similar to that found in the bark of *Pinus leiophylla* (5.8%), *Pinus durangensis* (6.4%) (Rosales and González 2003), and in the bark of *Erythroxylon compactum* (5.6%) (Colín *et al*. 2013). However, the tannin content in *E. crassipes* was lower than the value reported as suitable for commercial potential (Colín-Urieta *et al*. 2013).

Calorific Value

To our knowledge, calorific data for water hyacinth has not been published previously. The average calorific values of the water hyacinth presented in Table 5 are comparable to that of switchgrass (*Panicum virgatum*) (16.2 MJ/kg) as reported by Mendu *et al*. (2011) and are within the range of values determined for plants (10.04 to 19.19 MJ/kg) (Augustus *et al*. 2005). It is interesting to note that in this table, the calorific value of the original materials are slightly lower than those for extractives-free materials. This is contrary to the results presented by White (1987) for conifers, which might be due to the absence of resins in water hyacinth compared to conifers; due to this, the resin contributes positively to the calorific value of wood (Kollmann 1959). It is known that the calorific value of a lignocellulosic material depends on its lignin content (Browning 1963). By presenting our results of calorific values as a function of the lignin content (Table 1 and Fig. 1), the dependence is clearly observed. The variations can be explained by considering the differences in lignin composition, as reported by Kačik *et al*. (2012).

Table 5. Calorific Values of Sections of Water Hyacinth (MJ/kg)

Collecting site	Samples	Original material	Extractives-free material	Holocellulose	Runkel lignin
TR	Roots	15.03 ± 0.08	14.21 ± 0.12	11.95 ± 0.54	16.33 ± 0.57
	Stems	13.12 ± 0.14	14.46 ± 0.13	12.66 ± 0.43	16.97 ± 0.18
	Leaves	14.89 ± 0.36	15.88 ± 0.28	12.93 ± 0.43	17.23 ± 0.11
Average		14.35	14.85	12.51	16.84
YL	Roots	14.33 ± 0.10	14.21 ± 0.01	13.03 ± 0.13	20.27 ± 0.30
	Stems	13.69 ± 0.03	14.46 ± 0.01	13.74 ± 0.25	20.90 ± 0.10
	Leaves	15.46 ± 0.15	15.89 ± 0.17	13.78 ± 0.09	21.17 ± 0.16
Average		14.49	14.85	13.52	20.78

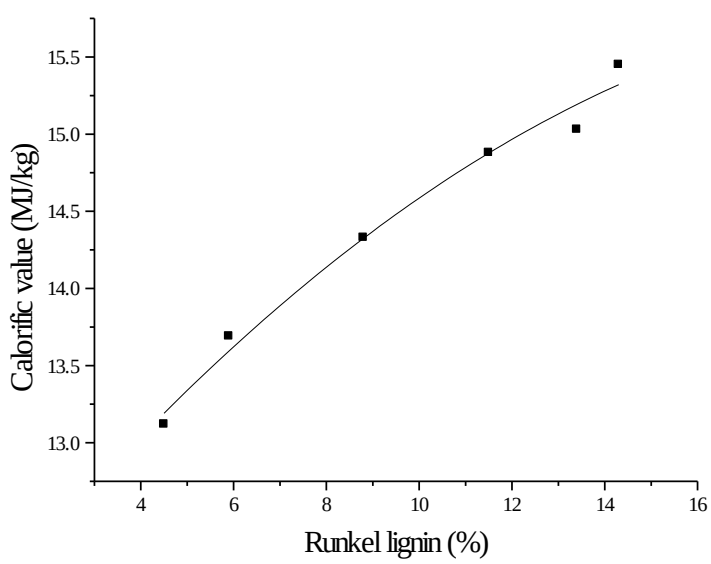

Fig. 1. Calorific value of water hyacinth as a function of lignin content

CONCLUSIONS

1. The composition and characteristics of plants from both sources slightly differed according to the environmental conditions of the two collecting sites. Higher ash content was found in the samples collected from TR compared with the samples obtained from YL.
2. Lignin and polysaccharide contents were relatively low. The amount of extractives was comparable to other lignocellulosic materials, the concentration of inorganic elements was high, and the calorific values were similar to those reported for other woods.
3. The average calorific values of the sample were in the following order: lignin > extractives-free material > original material > holocellulose.
4. No clear influence of ash content was observed on the calorific value of the original material; however, the influence of lignin content on the calorific value was clear.
5. The data collected in this study over the chemical composition and calorific value has led to the conclusion that this lignocellulosic material can be potentially useful for various applications, the use as compost, and as extractives substances source.

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