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THERMAL POTENTIAL OF THE MACROPHYTES *Eichhornia crassipes* (WATER HYACINTH) AND *Pistia stratiotes* (WATER LETTUCE)

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Abstract

Most of the world energy consumption comes from non-renewable sources, which are being depleted, so alternative sources are necessary. The purpose of this work was to evaluate the thermal energy potential of macrophytes *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce). These macrophytes were evaluated by gravimetric analysis, growth temporal determination, immediate analysis, and determination of the calorific value, under Cfb climate, Campos Gerais Region of Paraná, Brazil. The upper calorific value of macrophytes ranged from 11,459 kJ kg^{-1} for water lettuce to 14,158 kJ kg^{-1} for water hyacinth, lower than the wood used (around 18,000 kJ kg ^{1}). As for the dry mass productivity, the macrophytes varied from 6,889 kg ha^{-1} for water lettuce to 9,947 kg ha^{-1} for water hyacinth, also lower than the commonly used woods. The water hyacinth showed a higher potential than water lettuce. The values determined are lower, however, macrophytes are considered invasive in lakes have a high cost for maintenance, therefore, according to logistics, they can be an option as thermal energy.

Keywords: biomass, renewable energy, calorific value, biofuel.

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Introduction

With a view to sustainable development, the search for energy alternatives occupies a prominent place on the world agenda. Energy from biomass is highlighted as a renewable source of energy. Biomass can be defined as organic matter originated from agricultural and livestock activities, forestry or industrial residues. In addition to economic and environmental importance, biomass energy can assume social importance, being produced in smallholder farming systems.

Crops intended for use as biofuel feedstocks must present energetic and dry mass accumulation potentials. In these aspects, aquatic macrophytes stand out due to their high growth rates.

Aquatic macrophytes have important functions, recycling nutrients, removing nutrients in eutrophic environments, favoring periphyton communities, promoting habitat heterogeneity, protecting water bodies from erosion, among others.

However, when in disequilibrium, they have disordered growth. In this case tend to cuase problems in the environment such as the reduction of light penetration in aquatic environments; interference with the oxygenation of the environment; hinder power generation of hydroelectric plants; hinder river navigation; and fishing by increasing maintenance costs (Gastal Jr. *et al.*, 2003; Tarawou *et al.*, 2007; Tiwari *et al.*, 2007; Zheng *et al.*, 2009). In 2017, the detachment of macrophytes in a hydroelectric plant reservoir, in the state of Mato Grosso do Sul, paralyzed the operation of 10 generating units, causing a maintenance cost of US$ 900 thousand (CTG Brasil, 2019).

Through transpiration process, it can increase water loss by eight times in a water body (Souza and Lorenzi, 2005). In addition, macrophytes can provide shelter to insects that transmit the diseases of encephalitis, filariasis, and malaria (Kissmann, 1997).

However, macrophytes can be beneficially used for phytoremediation and in the provision of minerals through composting. (Lu *et al.*, 2010; Zacarkim *et al.*, 2014; Barrionuevo *et al.*, 2020). Therefore, this work aimed to evaluate the energy potential of macrophytes in Cfb climate, Campos Gerais Region of Paraná, Brazil.

Material and methods

This work was carried out in an artificial tank with continuous flow of water, used for amateur fish farming, in Ponta Grossa, Paraná, Brazil with coordinates UTM 615249.00 m E, 7219495.00 m S, zone 22J and altitude of 805 m a.s.l.

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The predominant climate is Cfb (Köppen), mesothermic (subtropical and temperate), always humid (without dry season) with mild summers, an average temperature in the warmer months (set-mar) being below 22 °C, and frequent frosts in the winter (Caviglione, 2000). The tank had a water surface of approximately 210 m^2 and depth ranging from 0.60 m to 1.50 m.

To start the experiment, the water body was depleted and all existing macrophytes were removed, then the tank was filled with water again. After ten days with water, the species of water hyacinth (*Eichhornia crassipes* Mart. (Solms)), covering approximately 50 m^2 of the tank surface, and water lettuce (*Pistia stratiotes* L.), covering approximately 10 m^2 of the tank surface, were placed on opposite sides of the tank. These macrophytes were chosen, because even though they are not endemic to Brazil, they are distributed in all regions (Amaral *et al.*, 2013).

Evaluations began 20 days after implantation. The first assessment aimed to correlate the mass of the crop by area. For the collection and dimensioning of dry mass in agricultural cultures, it is common to use a sample area of 1 m x 1 m, however in the case in vogue, because the amount of mass was greater, two wires, 50 x 50 cm and 20 x 20 cm, were tested.

The 20 x 20 cm area was selected and then 10 replicates per species were collected randomly. This material was weighted and dried in the shade until excess water was lost. After that, the water hyacinth plants were split into leaf, stem and root parts and the water lettuce plants into leaf and root (stem and root). All the material was placed in a forced air oven at 40 °C until constant mass.

A point was marked (x = 416 m e y = 398 m, Figure 1) from which it was possible to visualize the entire body of water. This point was used as reference for the photographic shoots of growth evaluation captured by the NIKON D 3100 14.2 MP camera. Seven images of the experimental area were made according to the dates: September 19th, November, 11th, January 26th, February 8th, February 13th and February 19th (2017/2018). The images were captured on days without clouds, between 12:00 and 13:00 h.

Photographs were initially processed with Inkscape v.0.91. After that, in a Geographic Information System (GIS), using the ArcGis v.10.2 program, the coordinate system was corrected by setting the grid (georeferenced). With vectorization, tank delimitation, evaluation and correction of the parameters of the photographs were performed: color, shape and texture, which made it possible to classify the surface cover of the tank as water hyacinth, water lettuce and water. The two species studied have very different morphoanatomical characteristics, which allowed easy classification. The growth analysis considered the movement of the crop in the water body.

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With the relative area, temporarily increased, for each macrophyte, multiplied by the dry mass of each macrophyte per unit area, determined as the first stage of the experiment, the temporal productivity of these cultures was obtained.

At the end of the experiment, February 19th, three samples of each species (20 cm x 20 cm) were collected and used for immediate analysis and calorific value.

Immediate analysis was carried out, where the content of volatile, fixed carbon and ash materials was determined. Samples were analyzed according to NBR 8112 (ABNT, 1986). In this case, to determine the moisture content, it was determined on an analytical scale (Quimis 500L210C), 1 gram (g) of the sample, in a porcelain crucible, was taken to the sterilization oven (Brasdonto), at a temperature of 100 ºC ± 5 ºC. The sample used to determine the moisture content was used for analysis of volatile materials. The crucible was placed in a muffle furnace (HydroSan,) at 950 °C ± 20 °C for 7 minutes. The content of volatile materials is the relative difference between the initial and final masses. After this procedure, a new sample of 1 g was dried and placed in a muffle oven (HydroSan,) at 700 ºC ± 10 ºC for 6 hours. In this case the remaining relative mass is the ash content. With the relative mass of volatile materials and ash in possession, the relative mass of fixed carbon is calculated by difference. For each plant component, three repetitions were performed.

For the upper calorific value, the samples were analyzed according to NBR 8633 (ABNT, 1984), using a calorimeter pump, IKA brand, model C200.

Results and discussion

Average values and dispersion of dry mass, according to the division among leaf, stem and root of water hyacinth (*Eichhornia crassipes*) and of water lettuce (*Pistia stratiotes*) by area are presented in Table 1. The shoot (leaf and stem) of the water hyacinth shows values higher than the dry mass of the submerged part (root). Such division (morpho-anatomical) is more academic than practical, because at harvest, the available machines collect the entire plant.

The growth in area (two-dimensional) of macrophytes water hyacinth and water lettuce were followed for 153 days, where seven determinations (photographic images) were performed. It was observed that the temperature, tended to increase gradually as the temporal advance of the experiment (spring/summer in the southern hemisphere).

Between the experiment establishment and the first determination/imaging (Spring), the mean of the minimum air temperature was 15.3 °C, while the mean of the maximum temperature was 24.9 °C, although with a large variation (ranging from 16.2 to 33.1 °C). After the third determination/imaging

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until the end of the experiment (Summer), the mean of the minimum temperature was 19.2 °C and the mean of the maximum temperature was 28.3 °C (ranging from 26.1 to 31.8 °C) [Weather Station of the Paraná Meteorological System (Simepar) of Ponta Grossa].

Table 1. Minimum, maximum, average values and coefficient of variation of dry mass* of water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) Ponta Grossa – PR.

Sample	Water content (g kg^{-1})	Maximum (kg ha^{-1})	Minimum (kg ha^{-1})	Average (kg ha^{-1})	Coefficient of variation (%)
			Eichhornia crassipes		
Leaf	518	2,695	1,152	1,751	30
Steam	840	6,890	3,225	4,433	33
Root	828	2,741	870	1,866	39
Total		12,326	5,247	8,050	
			Pistia stratiotes		
Leaf	858	4,090	1,936	2,774	25
Root	842	5,132	918	2,810	67
Total		9,222	2,854	5,584	

**dry mass after pass by forced air oven at 40 ºC, up to constant weight.*

The Figure 1 (a) shows the areas occupied by the two macrophytes on September 19th (first analysis) and Figure 1 (b) represents the last analysis (February 19th). For the water hyacinth, the initial occupied area of water was 64.51 m^2 after 153 days the area had increased 80 % to 116.57 m^2. Thus, it can be affirmed that in 153 days (Spring-Summer period in Cfb climate), the water hyacinth would have dry mass production ranging from 4.234 to 9.947 Mg ha^{-1} [Table 2 and Figure 1 (b)].

The relative growth measures according to dates of follow-up (70, 109, 129, 142, 147, 153 days) of the water hyacinth and water lettuce is showed at Table 2. The initial area of water lettuce was 10.31 m^2, reaching, after 153 days 18.03 m^2 an increase of 61%. Thus (spring/summer period in Cfb climate and 805 m.a.s.), water lettuce would have final dry mass production between 2,132 and 6,889 kg ha^{-1} [Table 2 and Table 3].

Macrophytes showed lower dry mass yields than energy woods and higher than most of the sub (co) products of agricultural crops (Table 3). One advantage of macrophytes, when compared to other biofuel feedstocks, is the use of this biomass would not cause changes in soil use (Bergier *et al.*, 2012).

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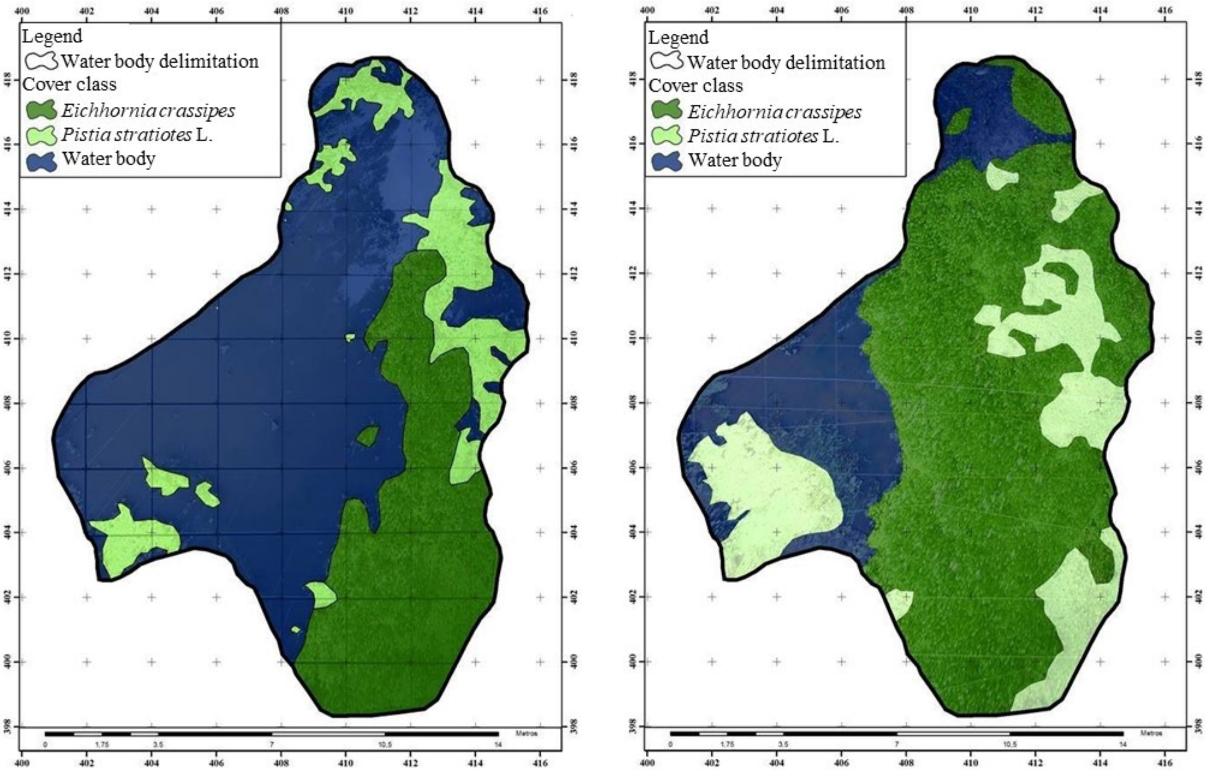

(A) (B)

Figure 1. Mapping of the area filled with water hyacinth and water lettuce on 19/09/2015 (A) and on 19/02/2016 (B).

Table 2. Area growth and relative area growth to the water hyacinth (*Eichhornia crassipes*) and for water lettuce (*Pistia stratiotes*) according to dates of follow-up, Ponta Grossa, Paraná, Brazil.

	Water hyacinth		Water lettuce	
Day	Area growth (m^2)	Relative area growth (m^2 m^{-2})	Area growth (m^2)	Relative area growth (m^2 m^{-2})
0	63.29	0	10.31	0
70	73.39	0.15	11.76	0.14
100	100.59	0.58	14.13	0.37
129	104.29	0.64	16.02	0.55
142	112.39	0.77	16.82	0.63
147	111.79	0.76	17.64	0.71
153	114.99	0.81	18.03	0.75

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Table 3. Dry mass per area of water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and biomass used as energy source and alternative biomass.

Species	Dry mass[1] (kg ha^{-1})	Author
Eichhornia crassipes[2]	4,234 a 9,947	
Pistia stratiotes[2]	2,132 a 6,889	
Eucalyptus grandis[3]		
wood	91,000 a 272,000	Goulart *et al.* (2003)
bark	9,000 a 20,000	
Pinus elliottii[4]		
shaft	161,300	Giongo *et al.* (2011)
twigs	15,800	
needles	7,700	
Sugar cane Straw[5]	5,770	Molina Junior *et al.* (1995)

[1]dry mass, dry mass after pass by forced air oven at 40 °C, up to constant weight [2] initial area of 1 ha, yield in 153 days (spring/summer)(Cfb, Köppen); [3] inventory with 21.9 years;[4] inventory with ten years; [5] inventory with 20 months.

The results of the immediate analysis are shown in Table 4. The mean values of fixed carbon and volatile materials were similar. The large ash content of the roots (Table 4) can be explained by the inorganic nature of the compounds that compose the ashes. These elements enter the plant by mass flow, through the roots being redistributed to the other tissues of the plant. Thus, it is reasonable that the roots, which constitute the gateway of these compounds, present higher concentrations.

The contents of volatile material found are high (Table 4). The samples had low fixed carbon content (0.12 for water hyacinth and 0.01 kg kg^{-1} for water lettuce) compared to the content of most woods and their respective charcoals (Table 5). A low fixed carbon value accompanied with a high value of volatile material can be an advantage, since the fixed carbon provides slower combustion, requiring a greater time in the combustion chamber. Studies of the energy within agricultural by-products, such as soybean straw (without grains), maize rachis and sugarcane straw, showed volatile to carbon ratios similar to the macrophytes (Table 5).

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Table 4. Mean and coefficient of variation of water content, volatile materials, ashes and fixed carbon of water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*), Ponta Grossa, Paraná.

	Water content		Volatile materials		Ashes		Fixed carbon	
Samples	Average (kg kg^{-1})	Coefficient of variation (%)	Average (kg kg^{-1})	Coefficient of variation (%)	Average (kg kg^{-1})	Coefficient of variation (%)	Average (kg kg^{-1})	Coefficient of variation (%)
Water hyacinth (*Eichhornia crassipes*)								
Leaf	0.19	4.1	0.77	8.6	0.10	9.5	0.13	5.6
Stem	0.18	8.4	0.76	7.7	0.12	9.2	0.11	5.7
Root	0.16	15.0	0.73	6.7	0.16	4.0	0.11	3.9
Plant[1]			0.75		0.12		0.12	
Water lettuce (*Pistia stratiotes*)								
Leaf	0.19	4.8	0.73	1.7	0.14	6.2	0.13	8.1.1
Stem	0.17	1.9	0.73	2.9	0.20	25.1	0.06	4.6
Plant[1]			0.73		0.18		0.10	

[1] *Average weight according to dry mass values (Table 1).*

The direct burning and continuous feeding values would suggest the macrophytes will have a uniform and rapid combustion when compared to charcoal. Macrophytes can be considered high value biofuels, because the ashes influence transportation costs, the combustion process, and the ashes can contribute to the corrosion of equipment.

According to the ash analysis, the macrophytes could be tested used as fertilizer or as a component in the construction industry (Horta *et al.*, 2010; Gunnarsson and Petersen, 2007; Fiuza *et al.*, 2017).

The high values of ash are energetically worrying, but they are similar to the values of *Jatropha curcas* in natura, charcoal and the charcoal of press cake, which are considered as potential for energy use (Vale *et al.* 2011).

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Table 5. Volatile, ash and fixed carbon content of *Eichhornia crassipes*, *Pistia stratiotes* and other materials used and with studies for energy utilization

Material	Volatile materials (kg kg^{-1})	Fixed carbon (kg kg^{-1})	Ashes (kg kg^{-1})	Author
Eichhornia crassipes	0.75	0.12	0.13	
Pistia stratiotes	0.73	0.10	0.18	
Corymba citriodora	0.20	0.80	0.01	Zanuncio *et al.* (2014)
Eucalyptus paniculata	0.23	0.76	0.01	
Cupressus lusitanica				Silva *et al.* (2014)
wood	0.17	0.18	0.01	
charcoal	0.29	0.70	0.02	
Acacia auriculiformes	0.84	0.15	0.01	Barros *et al.* (2009)
Ormosia paraenses	0.80	0.19	0.02	
Jatropha curcas				Vale *et al.* (2011)
Epicarp *in natura*	0.73	0.13	0.14	
Charcoal/epicarp	0.29	0.46	0.26	
Press cake *in natura*	0.74	0.14	0.08	
Charcoal/press cake	0.18	0.71	0.10	
Corn rachis	0.81	0.18	0.01	Paula *et al.* (2011)
Soybean plant	0.77	0.18	0.05	
Sugarcane plant	0.79	0.18	0.04	

The upper calorific value of the water hyacinth plant was higher than the water lettuce (Table 6), which may have relation considering the differences, albeit small, in the values of ash found in the two biomasses (Table 4). In terms of mass production (*Eichhornia crassipes*) also presented higher potential (Table 3).

The results of the upper calorific value for the water hyacinth (*Eichhornia crassipes*), and for the water lettuce (*Pistia stratiotes*) are shown in Table 6. For both the water hyacinth and the water lettuce, the upper calorific value of the roots (submerged part) was lower than the leaf and stem (aerial part). In both cases, these results were expected due to the ash content (Table 3).

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Table 6. Upper calorific value for botanical components, plant and coefficient of variation of water hyacinth (*Eichhornia crassipes)* and water lettuce (*Pistia stratiotes)*

Eichhornia crassipes			*Pistia stratiotes*		
	Average upper calorific value (kJ kg^{-1})	Coefficient of variation (%)		Average upper calorific value (kJ kg^{-1})	Coefficient of variation (%)
Leaf	15,966	1.67	Leaf	13,028	0.87
Stem	14,522	0.52	Submerged part	9,886	1.04
Root	11,564	0.94	Total*	11,459	
Total*	14,158				

** weighted average according to dry mass averages (Table 1).*

The upper calorific value (UCV) of the macrophytes was 25 to 50% lower than most of the presented sources (Table 7). Therefore, the use of this biomass as a heat source depends on the gravimetric yield and the logistical cost. The sources cited as having a better calorific value do not compete directly, however, they use soil as a substrate while macrophytes use water.

Although plant materials (by-products) from large-scale agricultural crops had similar volatile and fixed carbon values, the UCVs of these crops were higher than the macrophytes due to differences in the ash content (Table 5).

The macrophytes water hyacinth and water lettuce present intermediate energy potential compared to other feedstocks previously studied and those currently in use; due to the low immediate analysis valuesand average upper calorific values.

Therefore, additional studies of logistics and ash quality can help determine the feasibility of using macrophytes as biofuel feedstocks or fertilizers. Logistics is understood as the relationship between the amount of energy transported, which would be the dry mass of macrophytes minus the amount of water, and the distance to be transported.

Simple and inexpensive drying processes, using direct solar radiation, can greatly reduce the amount of water to be transported, which can enable longer transport distances, as well as the use of such biomass. The characterization of the ash may indicate its use as a fertilizer for traditional agricultural crops, as well as for organic production systems, as they have low solubility.

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Table 7. Comparison of the upper calorific value of water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) with other sources

Material	Upper calorific value ($kJ\ kg^{-1}$)	Author
Water hyacinth (*Eichhornia crassipes)*	14,158	
Water lettuce (*Pistia stratiotes)*	11,459	
Piptadenia gonoacantha (alligator wood)	19,455	Damásio *et al.* (2013)
Cupressus lusitânica		Silva *et al.* (2014)
wood	19,292	
charcoal	27,421	
Acacia auriculiformes	18,338	Martins *et al.* (2016)
Ormosia paraensis	18,330	
Corymbia citriodora	19,238	Zanuncio *et al.* (2014)
Eucalyptus urophylla	19,794	
Jatropha curcas		Vale *et al.* (2011)
epicarp *in natura*	14,480	
charcoal/epicarp	16,543	
press cake *in natura*	21,430	
charcoal/press cake	26,078	
Corn rachis	19,309	Paula *et al.* (2011)
Soybean plant	18,848	
Sugarcane straw	18,053	
Sugarcane Straw	18,091	Molina Junior *et al.* (1995)

Conclusions

The water hyacinth (*Eichhornia crassipes*) showed dry mass yield ranging from 4,234 to 9,937 kg ha^{-1} while water lettuce (*Pistia stratiotes*) ranged from 2,132 to 6,889 kg ha^{-1}.

The water hyacinth content of fixed carbon was 0.12 kg kg^{-1} and ash content 0.127 kg kg^{-1}, while the water lettuce presented fixed carbon contents of 0.01 kg kg^{-1} and ash content 0.18 kg kg^{-1}.

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The water hyacinth presented a higher mean of upper calorific value (14,158 kJ kg^{-1}), then water lettuce (11,459 kJ kg^{-1}).

The water hyacinth had a higher energy potential than the water lettuce.

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