



Water Hyacinths–biomass Production Potential at a Waste Water Treatment Plant

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Authors' contributions

This work was carried out in collaboration among all authors. Author KD supervised the study, wrote the final draft and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2020/v23i230138

Editor(s):

(1) Dr. Anil Kumar, Devi Ahilya University, India.

Reviewers:

(1) Peter E. Akhator, University of Benin, Nigeria.

(2) Ahmet SIVACIOĞLU, Kastamonu University, Turkey.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/55757>

Original Research Article

Received 02 February 2020

Accepted 09 April 2020

Published 14 April 2020

ABSTRACT

The growth of *Eichhornia crassipes* under outdoor conditions was examined during a 42-day test in a wastewater treatment plants primary clarifier, trickling filter and secondary clarifier using municipal residential wastewater as the chosen supplier of nutrients.

Test results showed that *Eichhorn crassipes* plants gained a significant amount of biomass in a short period. Plants could increase their biomass 15.1-fold from the initial weight of 457.6 g to 6898.8 g for the primary clarifier and 12.6-fold from the initial weight of 288.2 g to 3635.0 g for the secondary clarifier. Plant growth in the trickling filter was limited by factors such has as observed bird picking, *Cladophra* algae growth in the trickling filter and on the roots of *Eichhorn crassipes*, and intermittent exposure to nutrients contained in the municipal residential wastewater.

Keywords: Biomass production; waste water; waste water treatment plant; water hyacinth; water hyacinth grow.

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1. INTRODUCTION

Eichhornia crassipes, also known as water hyacinth, is an aquatic plant, and is native to South America, Amazon basin [1]. *Eichhornia crassipes* is one of the worst, highly invasive aquatic plant and can be found in 5 continents and more than 50 countries [2] on earth. Regions and area affected by *Eichhornia crassipes* including Central America, central and western Africa, south-east Asia, and south-eastern USA [3].

Optimal growth for *Eichhornia crassipes* happens at water temperature from 28°C to 30°C with rich nutrients like nitrogen, phosphorus, and potassium [4,5]. *Eichhornia crassipes* has an extremely high growth rate in the freshwater system in an ideal condition. It can double in size every 5 days in Australia [3]. Another research shows that *Eichhornia crassipes* can double its population in two 2 weeks, generating a huge amount of floating biomass [6]. One hectare of healthy *Eichhornia crassipes* can weigh as much as 415 metric tons [7].

Eichhornia crassipes tolerates water level fluctuations, seasonal flow velocity variation, nutrient availability, pH, temperature and toxic substances [8]. *Eichhornia crassipes* was reported to tolerate salinities from 0 to 8.8 ppt [9]. It can survive at water temperature below 5°C for a short period [10] and at water temperatures up to 30°C [3,5]. These characteristics make *Eichhornia crassipes* one of the worst invasive weeds in the world and represent a treat to the environment [5].

Eichhornia crassipes can cause several serious problems. It can disrupt native species' diversity through hybridization, ecosystem modifications and functioning [11,12]. It may change the aquatic habitat structure, and negatively affecting biological communities [13]. *Eichhornia crassipes* can also have a risk for human health. Its mat-like nature leads to the concentration of micro-organisms around the plant roots and shoots, it can increase the pests population (like mosquitos) and may bring many diseases, such as ancephalitis, filariasis, malaria and schistosomiasis [8,14-18].

Despite those disadvantages *Eichhornia crassipes* may have or cause for freshwater bodies and the environment, we could on the contrary, use its special characteristics like tolerating water level fluctuations, seasonal flow

velocity variation, nutrient availability, pH, temperature and uptake of toxic substances and growth rate potentially as a biomass feedstock for the production of biogas [8]. In addition, the sludge produced as a byproduct from the anaerobic digestion has high amounts of nutrients which would make it ideal for a fertilizer [19] and can offset the cost of operating.

The focus of this study is to assess the growth potential of *Eichhornia crassipes* using Municipal Residential Waste Water (MRWW) as a nutrient source at a wastewater treatment plants trickling filter, primary and secondary clarifier to assess *Eichhornia crassipes* as a potential biomass source for anaerobic digestion. The study was carried out at the Cleanwater Educational Research Facility (CERF) located at the Village of Minoa, New York, Waste Water Treatment Plant (WWTP).

2. MATERIALS AND METHODS

The *Eichhornia crassipes* plants, shown in Fig. 1, used for this study are third-generation plants and came from fishpond where they were used as ornamental plants from May to October. During the wintertime when temperatures drop below 10°C some of the plants were nurtured in a 100 l fish tank at 20°C and reused for the pond starting end of April when temperatures are above 10°C. The plants were originally obtained as ornamental plants from a nursery in Florid, USA.

The growth study with *Eichhornia crassipes* was carried under natural conditions for 42-days at the Primary Clarifier (PC), Trickling Filter (TF) and Secondary Clarifier (SC) at the Minoa CERF. Fig. 2 shows the process flow sketch of the WWTP section the study was conducted. Approximate 950,000 l/d of Municipal Residential Sewage (MRS) from the influent structure is first directed into a PC. After PC treatment, half of this flow is directed to a constructed wetland. The remaining MRS is directed into the influent box (IB). Both Waste Water (WW) streams are mixt in the IB and are then forwarded into a trickling filter. After the TF treatment, the WW passes through a secondary clarifier and a disinfection unit before it is discharged into a stream [21,22].

At the start of the growth, study marked and weighted *Eichhornia crassipes* plants were placed at the end of the PC, the TF and the SC (Fig. 3a to c).



Fig. 1. Water hyacinth (*Eichhornia crassipes*) [20]

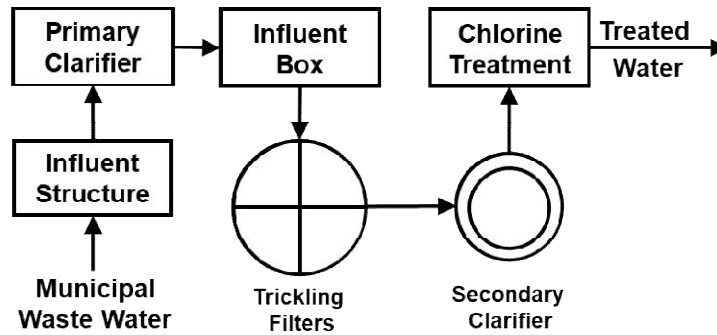


Fig. 2. Waste water treatment plant process flow sketch [23]



Fig. 3. *Eichhornia crassipes* placed in a) Primary clarifier, b) Trickle filter, c) Secondary clarifier [24]

The water hyacinths plant biomass yield was determined every 7 days during the 42-day study. Before weighing the plants were carefully removed and dried with a paper towel. After drying each of the *Eichhornia crassipes* plant placed on an analytical scale with an empty container large enough to hold the *Eichhornia crassipes* plant. Prior to weighting the scale was tared to account for the weight of the empty container.

The outside air Temperature (t) in [°C], Relative Humidity (RH) in [%] and Precipitation (PCPN) in [mm] was recorded during the 42-day study.

The WWTP influent MRW stream fluctuates based on the time and day of the year and can be in the range between 1.0 to 12.0 mg/l for Total Phosphorous (TP), 10 to 30 mg/l of ammonium (NH₃), 15 to 45 mg/l for Total Kjeldal Nitrogen (TKN), Chemical Oxygen Demand (COD) from

50 to 200 mg/l, Total Suspended Solids (TSS) are in the range of 150 to 250 mg/l, and the 5-day Biological Oxygen Demand (BOD₅) ranges from 50 to 350 mg/l at an average temperature of 15°C [25].

Phosphorous levels expected at the TF can be as high as 5.0 mg/l and as low as 1.2 mg/l.

Effluent parameters permitted to reach a maximum for TP of 0.8 mg/l, NH₃ of 0.5 mg/l, TKN of 1.3 mg/l, CBOD <4 mg/l, TSS of <4 mg/l and BOD₅ of <4 mg/l [25].

3. RESULTS AND DISCUSSION

Fig. 4 shows the biomass gain in gram of the twenty *Eichhornia crassipes* plants used during the 42-day experiment. Seven of the twenty plants were placed in the PC and SC and 4 plants were placed in the TF. The seven *Eichhornia crassipes* plants placed in the PC had a 15.7 fold biomass gain from the initial weight of 457.6 g to 6898.8 g. The four *Eichhornia crassipes* plants placed in the TF had a 1.13 fold

increase in biomass from the initial weight of 141.0 g to 159.7 g and the seven *Eichhornia crassipes* plants placed in the SC had a 12.6 fold increase in biomass from the initial weight of 288.2 g to 3635.0 g.

Fig. 5 shows the outside temperature, relative humidity and precipitation for the 42 day trial period measured at 12:00 pm. During the test period a total of 72.3 mm precipitation was received. The outside temperature was between 17°C and 31°C, and the relative humidity was between 34% to 98%. The temperature of the MRS fluctuated between 15°C and 18°C at the time of sampling.

The individual biomass gain for each of the twenty *Eichhornia crassipes* plants during the 42-day test phase is shown in Figs. 6, 7 and 8. Each of the plants was weighted and labeled separately prior to testing. Seven plants were placed in the PC, four in the TF and seven in the SC. Each of the plants was carefully removed every seven days and dried with a paper towel prior to weighting.

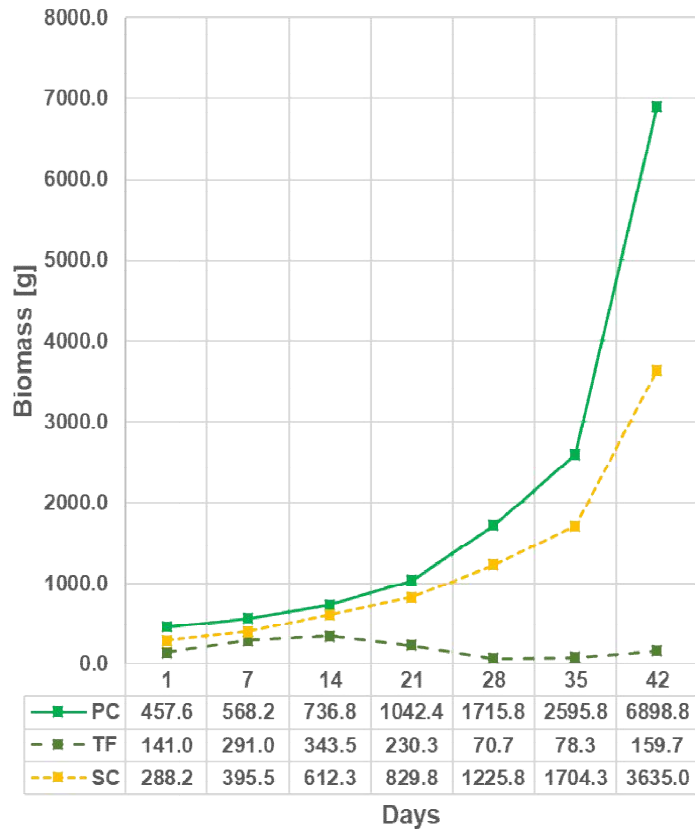


Fig. 4. Total biomass yield of *Eichhornia crassipes*

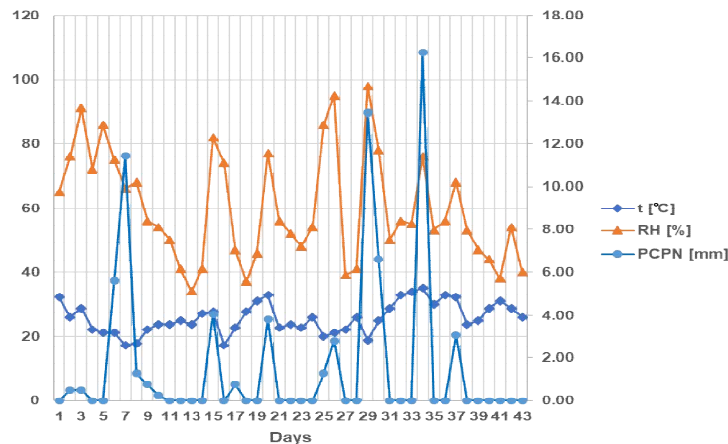


Fig. 5. Temperature, relative humidity and precipitation

3.1 Primary Clarifier

Seven *Eichhornia crassipes* plants put in the PC during the 42-day test phase. The biomass gain is shown in Fig. 6. Each of the plants was labeled separately and carefully removed and dried with a paper towel prior to testing.

Fig. 6 shows the individual plant grow during the 42-day test phase. Plant one grew from its initial weight of 11.3 g to 49.4 g representing a 43.4-fold increase in biomass. Plant two grew from its initial weight of 12.3 g to 683.8 g representing a 55.6-fold increase in biomass. Plant three grew from its initial weight of 30.7 g to 484.7 g representing a 37.7-fold increase in biomass. Plant four grew from its initial weight of 43.9 g to 1134.7 g representing a 25.8-fold increase in biomass. Plant five grew from its initial weight of 40.10 g to 1206.4 g representing a 30.1-fold increase in biomass. Plant six grew from its initial weight of 128.9 g to 3080.1 g representing a 23.9-fold increase in biomass. Plant seven grew from its initial weight of 21.0 g to 959.5 g representing a 44.7-fold increase in biomass. The overall gain in biomass of all seven plants is 12.6-fold from the initial weight of 288.2 g to 3635.0 g during the 42-day test period, or a biomass increase of 2.1 times per week.

3.2 Trickling Filter

Four *Eichhornia crassipes* plants were placed in the TF during the 42-day test phase. The biomass gain is shown in Fig. 6. Each of the plants was labeled separately and carefully removed and dried with a paper towel prior to testing.

Fig. 7 shows the individual plant grow during the 42-day test phase. Plant one grew from its initial weight of 14.5 g to 46.6 g representing a 43.4-fold increase in biomass. Plant three grew from its initial weight of 41.3 g to 113.1 g representing a 2.7-fold increase in biomass. Plant two and four grew from their initial weight of 49.1 g and 36.1 to 95.7 g and 49.7 g during a 21 day grow period representing a 1.9- and 1.4-fold increase in biomass. After the 21st day all plants suffered animal picking in the TF which lead to the destruction of the plant two and four and severe damage to plant one and two. The following additional reasons or a combination thereof could be linked to the low growth rate of *Eichhornia crassipes* plants in the TF:

First, the plants roots were covered over the first 21 days of testing with *Cladophra* algae specie [22], a filamentous green algae that grows attached to solid substrates [26,27]. This resulted in a slower growth rate after the first week and a decline in growth after the second week as shown in Figs. 7 and 6. In addition, earthworms which live with the *Cladophra* algae species in a symbiotic relationship in the trickling filter [21], appeared in the *Cladophra* covered roots of the *Eichhornia crassipes* plants after the second week of testing.

Second, the *Eichhornia crassipes* plants roots were not constantly exposed to water due to the nature of a trickling filter operation where water is sprayed on the *Eichhornia crassipes* plants and roots approximately every 15 seconds. The water then drained downwards in the trickling filter, allowing only a short contact time which is most likely not enough to uptake the nutrients available.

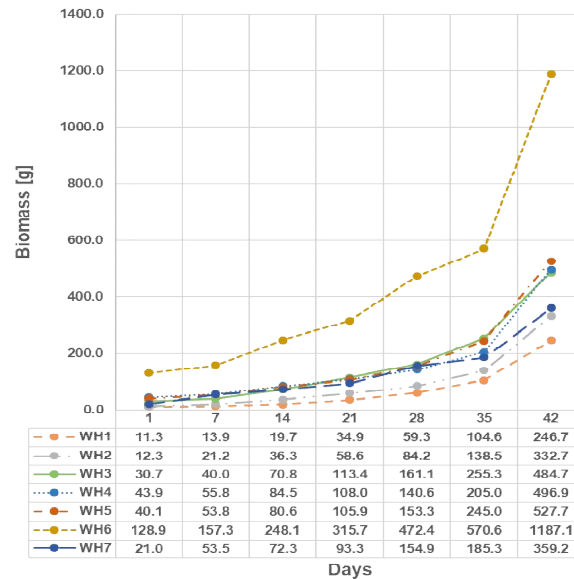


Fig. 6. Biomass gain of *Eichhornia crassipes* in the primary clarifier

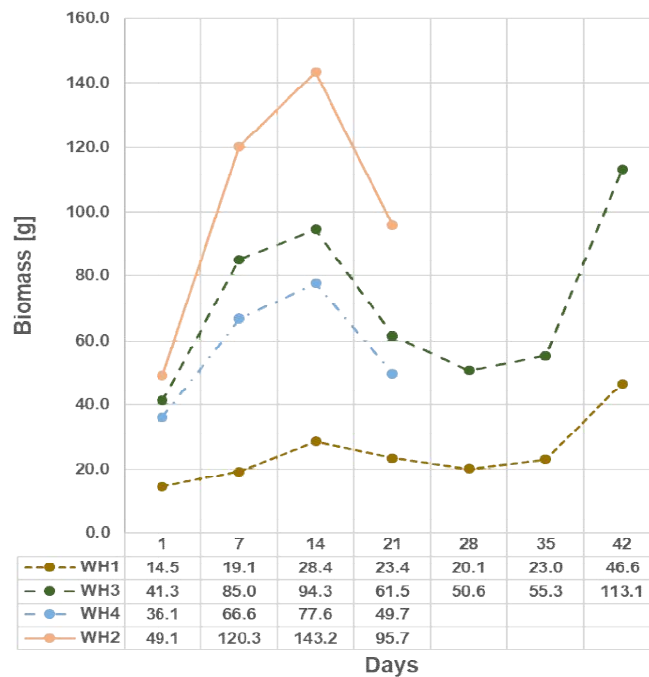


Fig. 7. Biomass gain of *Eichhornia crassipes* in the trickling filter

Third, the algae cover of the root system might have inhibited the growth rate of the *Eichhornia crassipes* plants by not allowing enough nutrition to reach the roots due to *Cladophora* nutrition uptake. The water was sprayed on the *Eichhornia crassipes* plants and roots approximately every 15 seconds. The water then

drained downwards in the trickling filter, allowing only a short contact time which is most likely not enough to uptake the nutrients available.

However, plant one and two could recover and showed a 2-fold and 1.9-fold biomass gain from 23.4 g to 46.6 g and 65.1 g to 113.1 g

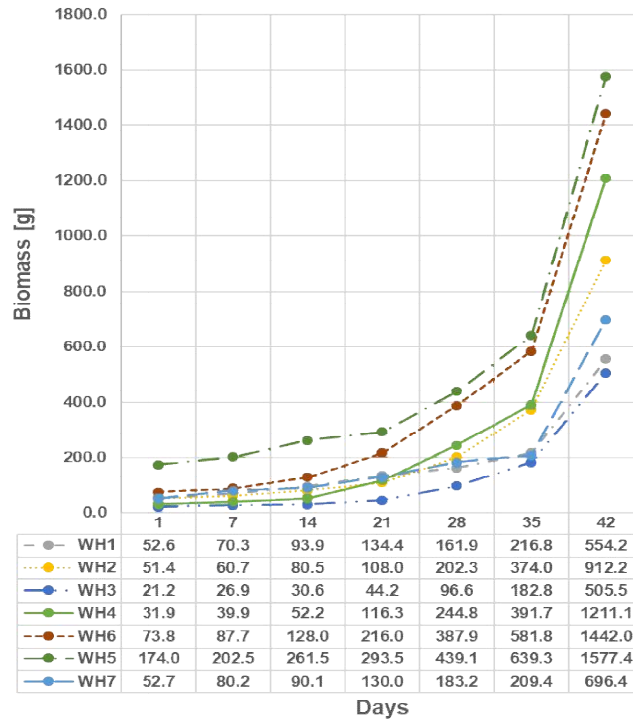


Fig. 8. Biomass gain of *Eichhornia crassipes* in the secondary clarifier

respectively. The overall gain in biomass of all four plants is 1.1-fold from the initial weight of 141.0 g to 159.7 g.

3.3 Secondary Clarifier

The seven *Eichhornia crassipes* plants in the SC during the 42-day test phase is shown in Fig. 8. Each of the plants was labeled separately and carefully removed and dried with a paper towel prior to testing.

Fig. 8 shows the individual plant grow during the 42-day test phase. Plant one grew from its initial weight of 52.6 g to 1284.1 g representing a 24.4-fold increase in biomass. Plant two grew from its initial weight of 51.4 g to 1789.1 g representing a 34.8-fold increase in biomass. Plant three grew from its initial weight of 21.2 g to 907.8 g representing a 42.8-fold increase in biomass. Plant four grew from its initial weight of 31.9 g to 2087.9 g representing a 65.5-fold increase in biomass. Plant five grew from its initial weight of 174.0 g to 3587.3 g representing a 20.6-fold increase in biomass. Plant six grew from its initial weight of 73.8 g to 2917.2 g representing a 39.5-fold increase in biomass. Plant seven grew from its initial weight of 52.7 g to 1442.0 g

representing a 27.4-fold increase in biomass. The overall gain in biomass of all seven plants is 15.1-fold from the initial weight of 457.6 g to 6898.8 g during the 42-day test period or a biomass increase of 2.5 times per week.

3.4 Other Results and Observations

The presented data shows that water hyacinth had a significant grows rate during the 42-day test phase in the PC and SC as shown in Fig. 9 a) and b) in comparison to Fig. 3 a) and c), and therefore can be a viable biomass resource if grown in MRW.

Fig. 10 shows the maximum root length measured up to 15 cm for *Eichhornia crassipes* placed in the PC and up to 60 cm for plants placed in the SC. *Eichhornia crassipes* tends to develop longer roots with a more darker color in the SC were nutrients such as nitrogen and phosphorus are already below the discharge limit of 0.8 mg/l for TP and 0.5 mg/l for NH₃. This observation is in concurrence with an observation by Sookna and Wilkie [29] were harvested plants showed a similar pattern if grown in undiluted and dilute wastewater.

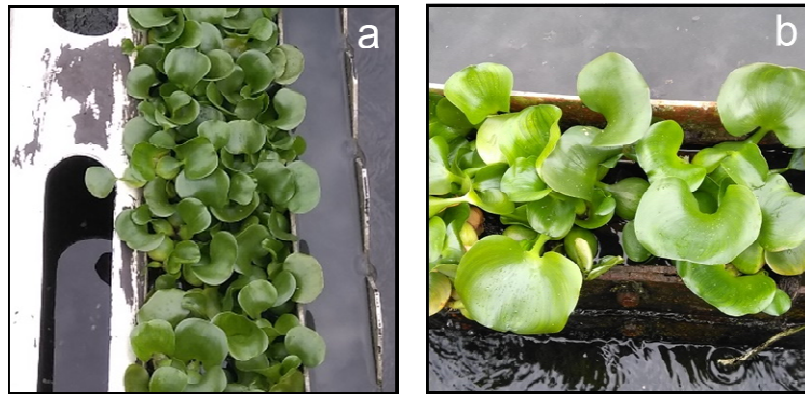


Fig. 9. *Eichhornia crassipes* in a) Primary clarifier, b) Secondary clarifier after 42 days of growth [28]



Fig. 10. Root length of *Eichhornia crassipes* in the primary (left) and secondary clarifier (right) [30]

4. CONCLUSION

Eichhornia crassipes grew very well in both the SC and PC using MRWW as a nutrient source and therefore can be considered a viable biomass resource. Application in TF might be limited but feasible.

Test results show that *Eichhornia crassipes* plants gain a significant amount of biomass in a short period of time when grown in MRWW. *Eichhornia crassipes* plants could increase their biomass during the 42-day test period 15.1-fold from the initial weight of 457.6 g to 6898.8 g for the PC and 12.6-fold from the initial weight of 288.2 g to 3635.0 g for the SC. In the TF plant growth overall was 1.1-fold from the initial weight of 141.0 g to 159.7 g. Factors such as

observed picking by birds, *Cladophra* algae growth on plant roots, and intermittent exposure to nutrients contained in the water played a significant role for plants placed in the TF.

Root length and color of *Eichhornia crassipes* is dependant on nutrients available in the water source.

This result compares well to findings of an earlier laboratory and outdoor study [5] as well as findings by Schardt and Hasan [7,31].

However, factors such as climate, contaminant concentration, retention rate and weather conditions may play an important role for plant growth and need to be taken in consideration for further studies.

ACKNOWLEDGEMENTS

Authors would like to express sincere gratitude to the ESF TRINITY Institute and the Fujian Province of the People Republic of China that provided funding for this project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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