Biogas production from beach casted brown seaweeds of red sea coast of Massawa, Eritrea

Authors & Affiliation:

Berhane Teklehaimanot, Awet Adhanom*, Elias Meharizghi, Fisseha Tekleweini, Habtemariam Kidane, Merhawi Beyene and Zebib Tsehaye

Department of Marine Food and Biotechnology, Massawa College of Marine Science and Technology, Massawa, Eritrea

Corresponding Author:

Awet Adhanom Berhe

ISSN 0799-3757

http://caribjscitech.com/

Abstract:

The beach casted brown seaweed *Sargassum spp.,* from Eritrean Red Sea has been used as a feedstock for biogas production at laboratory batch scale. The extensively parameters of water/solid ratio (concentration), temperature, and pretreatment in batch scale were investigated. Several pretreatment measures were investigated and it was found that drying and size reduction (maceration) was effective for the production of biogas. The mesophillic temperature of 30-40^{0}C was found to be optimal for enhanced production of biogas. In addition an optimal production was achieved in the specific retention time of 48h with a concentration of 0.11g/ml. The present study has thus shown that beach casted brown seaweeds are quite promising feedstock for biogas production.

Keywords: Anaerobic digestion, biogas, marine biomass, brown seaweeds

Introduction:

The growing demand for energy, hikes in oil prices, depletion of fossil fuels, and the increasing concern for environmental issues have boosted researchers to develop new technological processes to obtain clean and sustainable energy through the utilization of renewable energy sources (Gurung *et al.*, 2012). Furthermore, the world energy demand has increased significantly during the new millennium and is predicted to be 700 quadrillion BTU in 2030 from 400 quadrillion in 2000 (World Energy Outlook, 2008). Hence, most researchers nowadays are focusing in search for an alternative source of energy that are eco-friendly, with longer availability and lower generation period to extract and use the energy (Kelly and Dworjanyn., 2008).

In recent years marine biomasses especially seaweeds have attracted many researchers as biomass for biogas production. Seaweeds have high water content (70-90%), carbohydrate (25-60%), low lignin and cellulose content (1-7%) on dry weight make them an ideal material to be approximately hydrolyze completely and converted into methane (CH_4) gas (Bruton *et al.*, 2009: Chang *et al*., 2010). They have also number of potential advantages compared to terrestrial plants because of its higher biomass yields and its cultivation in seawater does not compete for the use of freshwater or arable land (Karlsson *et al*., 2014). Kelly and Dworjanyn (2008) have reported that, brown and green seaweeds are good candidates of feedstock for producing biogas because of their high methane yields.

Eritrea has a long coastline of 2,234 km^2 of Red Sea with a number of bio-diversified and unprecedented marine biota including seaweeds. Comparative survey of seaweeds from Red Sea, Eritrea as well as from other coasts of the western Indian Ocean have revealed that the regional distribution of seaweeds in red sea is very patchy and the area seems to be under sampled (Ateweberhan and Prud., 2005). In addition, biogas or bio-energy potency of these biomasses especially for biogas production is still underutilized.

Seaweeds such as *Laminaria sp*., *Porphyra sp*., *Undariasp*., *Eucheuma*sp., *Gracillaria*sp., and *Sargassum* species have been found to be economically valuable and they can be used as feedstock to produce biogas (Sitompul *et al.*, 2012). Sargassum species are one of the brown seaweeds that commonly occur worldwide as well as in many coastal areas of Eritrea and are considered as a potential renewable marine resource because of their great abundance. These biomasses are worth considered as one of a potential alternative aquatic energy crops (Bruhn *et al*., 2010). In addition, the valorization of these beach casted brown seaweeds for biogas would greatly improve the economic concept of beach cleaning management and provide the opportunity to reduce marine pollution through dissolved phosphate, nitrate, and heavy metals, thereby presenting an additional environmental benefit to this overall concept (Barbot *et al*., 2015).

Materials and Methods:

Sample collection

Beach casted seaweeds of *Sargassumspp* were collected from Gurgusum (Fig. 1) beach (15° 40' N, 39° 25' E) coastline of Massawa. Samples were collected by hand picking and stored in plastic bags and transported to the laboratory for pretreatment.

Figure 1: seaweed collection site (Gurgusum beach - 15° 40' N, 39° 25' E)

Pretreatment

The collected beach cast seaweeds were washed thoroughly with tap water to remove salt and grits remained on the seaweeds, while some are left untreated as control. The control and pretreated seaweeds were dried by hanging method and sun dried by spreading on floor (Fig.2 A and B) for seven days. The dried Samples were then size reduced by beating with stick (Fig.2 C). In some cases, further size reduction was done by maceration (Fig.2 D).

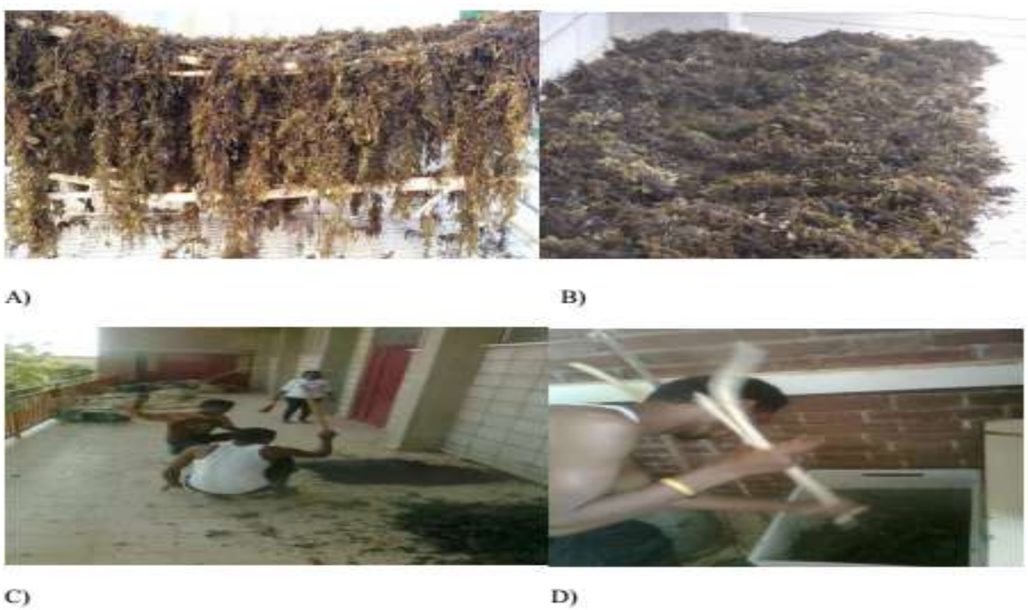

Figure 2: Pretreatment Measures A) Drying by hanging-drop, B) Drying on floor spread, C) Size reduction by (beating) and D) Soaking (macerating)

Bio-digester design

The bio-digester vessels used were six plastic containers of 5 litre capacity having dimension of width 11cm, 29cm height and 16cm length each. The lid of the vessels was drilled to connect with gas collecting bags. All perforations were properly sealed with adhesives to make the whole of the bio-digester system airtight.

Bio-digestion system

After pre-treatment, the dried samples were weighed and added directly in to the bio-digester. While remaining samples were macerated for about 7 days and then transferred in to the 5 litre bio-digesters. In average the bio-digesters were retained for 1-7 days. The plastic bio-digesters were manually shaken randomly three times in a day for 15 minutes.

Gas collection and quantification

The gas produced during bio-reaction from the bio-digesters were collected in plastic gas holder balloons with the capacity of 1500mL liquid volume (Fig.3), and gas measurement was done by liquid displacement method (Barbot., 2014; Hussain and Dubey., 2017) (Fig.4 a and b) volumetrically and the result were reported in ml/mg.

$$\text{Volume of } CO_2 \text{ ml/mg} = \frac{V_1 - V_2}{V_1}$$

$CH_4 = 100 - (\%CO_2)$ modified Mullen (1955) method (Andrew *et al*., 1995)

The accumulated crude biogas was tested for its presence by flame test. The gas was slowly released from the plastic balloons and put across lighted match in dark room.

Figure 3: Gas collecting bag filled with biogas

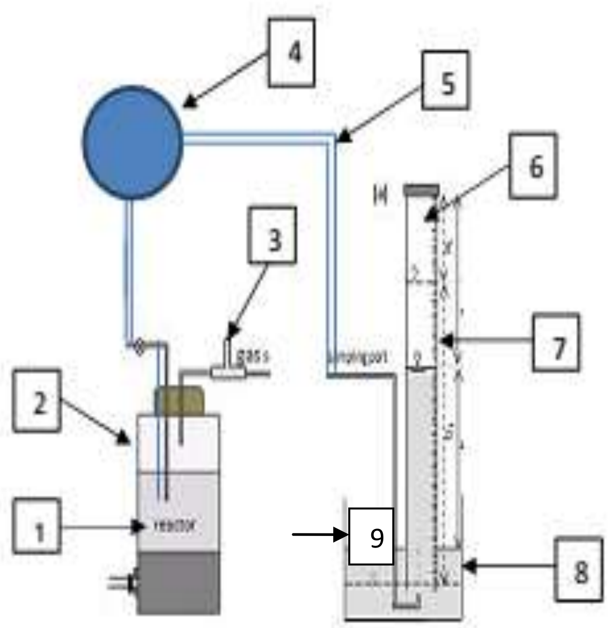

Figure 4: Diagram of experimental set up : 1-Digester feed, 2- Digester, 3- gas sampling port , 4- gas collector urine bag, 5- Tube, 6- Biogas, 7- Measuring cylinder (Gas receiver), 8- bath(container), 9- dilute sodium hydroxide solution, modified from (Parajuli., 2011: Rashed., 2014).

Results and Discussion:

Effect of physical Pre-treatment measures

It is hard to identify the most suitable pretreatment for all types of lignocellulosic materials (Hahn-Hägerdal *et al*., 2006). Physical pretreatment measures like washing, size reduction, drying, soaking, mixing were thoroughly investigated. Each pretreatment has advantages and drawbacks. The optimal operation depends on the characteristics of the materials. The main purpose of pretreatment for biogas production is to increase the accessibility to the building material of the sample (Liqian, 2011).

Effect of Washing

In these study, it was found out that, there was no much significant effect of washing on the biogas production rate but it was seen to affect the bio-digestion reaction especially by affecting the environmental condition of the reaction physically and chemically (Table 1). Similar results were obtained by Lars *et al*., (2008), suggesting that washing had no effect on the methane yield (Bruhn, *et al*., 2011). In addition, Kaspersen *et al*., (2016) reported to avoid sand, debris and other unwanted inorganic compounds that hinder anaerobic growth, separation or washing has been concluded to be both necessary and possible (Dessle., 2017).

Effect of drying (hanging versus floor spread)

The drying process had shown a conspicuous change in biogas production, in comparison to the control. This change in biogas production results could be attributed due to that the biochemical composition of the samples. Brown algae in contrast to red and green algal species have complex sugars which cannot be fermented easily. Therefore the regular anaerobic digestion treatment is non-viable and difficult, thus requiring a pre-treatment were the polysaccharides to be broken down into monomers before the hydrolysis step (Montingelli, 2014). In addition, among various drying methods investigated for biogas production the hanging dried samples showed much more production (Table 1).

Effect of Size reduction (physical- beating/chopping)

The complex polysaccharides present in brown seaweeds require a pre-treatment to be breakdown into monomers before the hydrolysis step (Montingelli, 2014). In support to these Sangaraju, 2012 revealed that there is improvement in the methane yield due to size reduction which can be attributed due to the fact that size reduction of samples cause more vulnerability to the microbes by increased the interaction of surface area and thus making the samples more easily used and thus enhanced the digestibility which resulted in higher metabolic rate and thus higher by-product.

Effect of Soaking

The effect of maceration was also investigated and was found that, it has an important effect on speeding up the reaction time and thus showing a significant increase in biogas produced in the retention time of 24-48h (Table 1). The water content of seaweeds makes it suitable for wet anaerobic digestion and thus increasing the biogas production as reported by Blidberg and Gröndal (2012).

Treatment type	Biogas accumulation intensity in ml						
	24h	48 h	72 h	96 h	120 h	144h	168 h
(C)	0	300	600	900	900	900	900
(WS)	0	300	900	900	600	600	600
(Wt)	0	600	900	1200	1200	900	900
(WDf)	300	900	900	600	600	300	300
(WDh)	300	1200	1200	1200	900	900	600
(WDS)	600	1200	1200	900	900	600	600
* (WDSr)	600	1500	1500	1200	1200	1200	900
(WDSrS)	600	1200	1200	900	900	600	600

Table 1: Effect of different physical treatment measures ((Untreated (control) (C); washed with seawater (WS); washed with tab water (Wt); washed + floor spread dried (WDf); washed + hanging drop dried (WDh); washed + dried + soaking (WDS); washed + dried +size reduced (WDSr); washed +dried + size reduced + soaking (WDSrS)) on biogas production.

Effect of sample concentration

The reaction conditions are influenced by many physico-chemical parameters. The organic loading rate (OLR) of seaweed sample in an anaerobic digestion is too high, the bacterial activity will stop, thus lower the biogas production Montingelli (2015). The overloading could also cause an initial increase followed by a decrease in biogas production by inhibiting the methanogens (Sangaraju, 2012). Simultaneously more diluted seaweed concentration mitigate the gas production by settling the solid particles at the bottom of the digester (Mahanta *et al*., 2005). In the present study an appropriate amount of sample concentration in accordance to the favorable conditions were investigated and was found that, a solution concentration of 0.1g/mL to be an optimal concentration for an enhanced biogas production through the process of anaerobic digestion.

Effect of Temperature:

In the present investigation the effect of temperature on production of biogas was assessed and the results were given in table 3. An optimum mesophillic temperature of 30-40^{0}C was found to be conducive for steady and balanced biogas production of biogas in comparatively short period of time. The room temperature in the months of January – March is 18-28^{o}C, during this period the production of biogas is very low and slow, this is as a result of the fact that the rate of organic matter conversion into biogas is minimized, since the activity of microorganisms is limited. As a result a longer residence time was taken for biogas production. Whereas, starting from the months of April up to October due to increase in temperature, therefore the biogas production was also increased. This increase is due to high growth rate of methanogens at 40^{0}C and exhibit high degrees of conversion of organic matter into biogas. As a result the stability and growth conditions of methanogenic microorganisms in the digester at mesophillic conditions was more balanced, more resistant to chemicals that inhibit digestion (Rashed, 2014).

Different month of the year	**Biogas accumulation intensity (estimated)in ml**						
	24 h	48h	72h	96h	120h	144h	168h
January (18-25^{0}C)	0	0	300	900	900	1200	600
February (18-25^{0}C)	0	0	300	600	600	900	900
March (18-25^{0}C)	0	0	600	900	900	600	300
April (20-28^{0}C)	300	600	600	900	1200	600	0
*May (25-37^{0}C)	600	900	1200	1500	1200	900	900
June (35-40^{0}C)	600	1200	1500	1500	900	0	0
July (35-45^{0}C)	600	1500	1200	900	600	0	0
August (38-45^{0}C)	900	1500	1500	300	0	0	0
September (30-38^{0}C)	600	900	1200	1200	900	600	300
October (25-32^{0}C)	300	900	900	1200	600	600	300
November (20-28^{0}C)	0	600	900	900	1200	900	0
December (20-28^{0}C)	0	300	900	1200	1500	900	0

Table 3: Effect of Temperature (recorded for different months of a year) on biogas production

Conclusion:

The seaweeds have less amount of cellulosic material and lack of lignin favors them as best candidates for production of biogas. As a core point of investigation, an advantage of short retention time (48-72h) for such significant biogas production (flammable) is achieved. An optimum condition with temperature of 30-40^{0}C, a pH of 6.8-7.5, a retention time of 48-72h and concentration of 0.1g/ml was found to be determinant for the enhanced yield of biogas with highest flammability. An overall estimated yield 50-60% flammable gas was achieved in this investigation. Therefore, it can be concluded that locally marine biomass (beach cast) can be used as house hold energy source with arranged supervisions to the public.

Acknowledgement:

The authors are thankful to Dr. Zerkeria Abdulkerim, Dean of Massawa College of Marine Science and Technology, Mr. Madhu Babu Kasimala, Department of Marine Food and Biotechnology for their support and encouragement during the work.

Reference:

1. Andrew, D.E., Lenore, S.C., Arnold, E.G. (1995). Standard methods for examination of water and waste water. *American public health association* 2-85: 2720-B,ISBN-0875532233.
2. Ateweberhan, M and W.Prud, H.W. (2005). A taxonomic survey of seaweeds from Eritrea. Department of marine biology and fisheries, *university of Asmara*. 50: 65–111
3. Barbot, Y.N., Falk, H.M., Benz, R. (2014). Thermo-Acidic Pretreatment of Marine Brown Algae Fucus Vesiculosus to Increase Methane Production—A Disposal Principle for Macroalgae Waste from Beaches. *J. Appl. Phycol*1–9, doi:10.1007/s10811-014-0339-x.
4. Barbot, Y.N., Thomsen, L., and Benz, R. (2015).Thermo-Acidic Pretreatment of Beach Macroalgae from Rügen to Optimize Biomethane Production—Double Benefit with Simultaneous Bioenergy Production and Improvement of Local Beach and Waste Management. *Marine drugs*,13(9), 5681-5705
5. Blidberg, E., Gröndal, F. (2012). Macroalgae Harvesting and Cultivation. In Compendium - *An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources* pp. 49-76
6. Bruhn, A., Dahl, A., Nielsen, H. B., Nikolaisen, L., Markager, S., Olesen, B., Arias, C., and Jensen, D. (2011). Bioenergy potential of *Ulvalactuca*, biomass yield, methane production and combustion. *BioresourceTechnology* **102**: 2595-2604.
7. Bruton, T., Lyons, H., Lerat, Y., Stanley, M., Bo. R.M . (2009). A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland. *Sustainable Energy Ireland* Page 64-68
8. Chang H. N., Kim N. J., Kang J., and Jeong C.M . (2010). Biomass-derived volatile fatty acid platform for fuels and chemicals. *Biotechnol. Bioproc. Eng.*, **15**: 1-10.
9. Dessle, F. (2017). Harvesting and utilizing beach cast on Gotland. Kth Royal Institute Of technology School of Architecture and the Built Environment, *Tritaim-ex*
10. Gurung, A., VanGinkel,W.S., Kang, W., Qambrani, A.N., Oh, S. (2012). Evaluation of marine biomass as a source of methane in batch tests: A lab-scale study. *Energy* 43: 396-401
11. Hahn-Hägerdal., B.Galbe, M., Gorwa-Grauslund, M.F., LidenG.zacchi G. (2006). Bioethanol- the fuel of tomorrow from the residues of today. *PubMed* PMD-17050014
12. Hussain, A., Dubey, S.K. (2017). Specific methanogenic activity test for anaerobic degradation of influents. *Appl. Water Sci* 7(2), 535-542.
13. Karlsson, A., Björn, A.k., Shakeri, Y.S., Bo H.S. (2014). Improvement of the biogas production process. *Biogas Research Center (BRC) Report* Page 5-6
14. Kaspersen, B.S., Christensen, T. B., Fredenslund, A. M., Møller, H. B., Butts, M. B., Jensen, N. H., Kjaer, T. (2016). Linking climate change mitigation and coastal eutrophication management through biogas technology: Evidence from a new Danish bioenergy concept. *Science of the Total Environment*, 541, 1124-1131
15. Lars, N., Peter, D., Karin, S. Jonas, D., Jørgen, B., Torben, B., Michael, B.R., Annette, B., Anne-Belinda, B., Henrik, B.N., Kristian, R.A., Per A., Zsofia, K., Stefan, H., Bo, Sander., Erik, R.S.(2011).Energy Production from Marine Biomass (Ulvalactuca). *PSO Project* No. 1-0050
16. Liqian, W., Mattsson, M., Rundstedt, J., Karisson, N. (2011). Different pretreatment to enhance biogas production-A comparison of thermal, chemical and ultrasonic methods. Master thesis, *Halmstad University*
17. Mahanta, P., Saha, U.K., Dewan, A., Kalita, P., and Buragohain, B.(2005). Biogas Digester: A Discussion on Factors Affecting Biogas Production and Field Investigation of a Novel Duplex Digester. *Journal of the Solar Energy Society of India*, Page 1-12
18. Montingelli, M. E., Tedesco, S., Olabi, A. G. (2015). Biogas production from algal biomass: A review. *Renewable and Sustainable Energy Reviews* 43: 961-972.
19. Mullen, P.W. (1955). Modern gas analysis. *Interscience publisher*. New York N.Y

20. Rashed, B.M. (2014). The Effect of Temperature on the biogas Production from Olive Pomace. *University Bulletin* – 3 (16): 135 - 148.
21. Sitompul, P. J., Bayu, A., Soerawidjaja H. T., Woo Lee, H. (2012). Studies of Biogas Production from Green Seaweeds. *International Journal of Environment and Bioenerg.*
22. Kelly, S. M and Dworjanyn, S. (2008). The potential of marine biomass for anaerobic biogas production: a feasibility study with recommendations for further research. *Scottish Association for Marine Science Oban*, Argyll, Scotland, PA37 1QA.
23. Sangaraju, R.C. (2012).Optimization of the anaerobic digestion process by substrate pre-treatment and the application of NIRS. *Aarhus University.*
24. Parajuli.P, (2011).Biogas measurement techniques and the associated errors. Department of Biological and Environmental Science Renewable Energy Programme.*University of Jyväskylä,* PA1.
25. World Energy Outlook. (2008). Taken from the website, www.worldenergyoutlook.org.