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METHANE PRODUCTION FROM THE RED SEAWEED GRACILARIA TIKVAHIAE

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Introduction

Research has been conducted for several years at the Harbor Branch Foundation on the cultivation of seaweeds as a possible source of biomass that can be converted to methane or other fuels (1,2). Of over 40 species of seaweeds examined, the rhodophyte *Gracilaria tikvahiae* had the highest sustained yield and can be vegetatively propagated indefinitely in an aquaculture system. Its productivity can be as high as any terrestrial crop on earth (3). This communication reports on the sustained anaerobic digestion of this species to produce methane and on how the loading rate affects gas production.

Materials and Methods

Two types of digesters were used in this study. The first (with a functional volume of 120 l) have been previously described (4). Digestion was started by adding the following into the digester: 20 l of anaerobic sediments collected from a nearby estuary, 20 l of seawater, and 5-25 kg wet weight of *Gracilaria*. Gas production began within 5 days. The seaweed was not pretreated (e.g. shredded) in any way prior to being loaded into the digesters. Loadings were made from October 1978 to June 1980, at approximately weekly intervals, usually with 5 kg wet weight; an equal volume of residue was removed. The contents of the digester were mixed manually at each loading; this was the only agitation employed. The digesters were kept at ambient temperature (30 C ± 5 C) during most of the year. During the cooler months of the first year (November-March), the digesters were kept partially submerged in a 3800 l circular water tank which was kept at approximately 30 C by an immersion heater.

The second type of digester was a sealed 3.8 l Nalgene wide-mouth bottle. An exhaust line from each digester was connected in series to two 3.8 l glass jugs; the first of these contained a 0.05 N sulfuric acid solution and the second one was empty. Biogas production was monitored as the displacement of liquid into the second jug. Each digester wa started with 2 kg wet weight of Gracilaria and inoculated wit 0.2 l of liquid from the larger digesters. After 7 weeks in batch mode, the digesters were loaded at rates corresponding to retention times (RT) of 10-60 days. The data reported her are for a 60 day period commencing 3 months after the initiation of the differential loading, a length of time adequate for steady-state conditions to be achieved.

Gracilaria fermented in this study was cultivated in outdoor cultures (5). Digesters were loaded once a week, when samples for gas analysis, volatile solids, and pH were taken. Biogas was measured 3 times a week. Gas data are reported for standard conditions of temperature and pressure (STP). Methane levels in the biogas were measured with a MSA Total Hydrocarbon Analyzer, calibrated against known amounts of methane. The volatile solids (vs) in plants or digester residue were determined after ashing dried samples (dried at 60 C for 48 hrs) for 4 hrs at 550 C in a muffle furnace.

Results

Stable, continuous anaerobic digestion of Gracilaria was

TABLE 1. Characteristics of stable, continuous anaerobic digestion of *Gracilaria tikvahiae*.

Temperature	30 C ± 5 C
Agitation	None
Load Composition	*Gracilaria* at 11% total solids, of which 58% is volatile solids
Mean Loading Rate	0.54 g volatile solids/l of digester/day
Normal pH Range	6.8-7.5
Gas Production	0.4 l/g volatile solids, at 60% methane
Bioconversion Efficiency	48%

maintained in the large (120 l) digesters for over 20 months, with an average gas production of 0.4 l/g vs, at 60% methane (Table 1). The heat of combustion of *Gracilaria* is 4.5 kcal/g ash-free dry weight (3) or 18.8 kJ/g vs. Since pure methane has an energy content of approximately 37.7 kJ/l, the above methane production represents an average bioconversion efficiency of about 48%.

As the retention time (RT) increased (i.e. loading rate decreased) from 10 to 60 days, the total production of biogas and methane (Table 2) as well as the percent methane and the reduction of total vs (Table 3) increased to maxima at a 30 day RT and then decreased at a 60 day RT. Biogas production and methane production on the basis of vs added increased up to a 60 day RT (Table 2) as did the percent vs reduction (Table 3). The amount of biogas and methane produced on the basis of vs destroyed (Table 2) was remarkably constant, except at a 10 day RT. Gas production at a 10 day RT was erratic and considerably less than all other RT's, and low pH (<6.0) was common at this high loading rate. The pH in the digesters increased as the RT increased. Bioconversion efficiency was maximal at the longest RT and was closely correlated with percent vs reduction.

Table 2. The effect of retention time (RT) on gas production in anaerobic digesters of Gracilaria tikvahiae.

RT	Biogas Production			Methane Production		
(days)	(l)	(l/g vs added)	(l/g vs destroyed)	(l)	(l/g vs added)	(l/g vs destroyed)
10	28.9	0.04	0.67	8.8	0.01	0.20
15	35.2	0.07	0.76	20.7	0.04	0.45
20	41.0	0.11	0.73	24.0	0.06	0.43
30	48.9	0.19	0.73	32.2	0.13	0.48
60	44.6	0.35	0.73	25.4	0.20	0.42

Table 3. The effect of retention time (RT) on biogas composition, pH, volatile solids reduction (VSR), and bioconversion efficiency in anaerobic digesters of Gracilaria tikvahiae.

RT	Biogas Composition	pH	VSR		Bioconversion Efficiency
(days)	(% Methane)		(g)	(%)	(%)
10	30.4	5.9	42.9	5.6	2.3
15	58.9	6.2	46.4	9.1	8.1
20	58.6	6.4	56.3	14.7	12.6
30	65.8	6.7	66.9	26.2	25.3
60	57.0	7.1	60.9	47.7	40.0

Discussion

This study demonstrates that Gracilaria can be fermented to produce methane for a sustained period of time. Both the gas production and bioconversion efficiency compare favorably witl those of other biomass substrates (e.g. 6,7). The emphasis i this study has been on non-intensive digestion (i.e. energy inputs into the digesters are minimized). Procedures such as continuous agitation or heating would increase gross methane production; however, the net energy yield could decrease as

Jewell (8) has observed for the digestion of cow manure.

This study has shown how loading rate affects gas production and other digestion characteristics. This information will be helpful in designing large-scale digesters with Gracilaria as a substrate. The rate of gas production is maximal at a 30 day RT, but, if the digesters were relatively inexpensive to construct, a longer RT (e.g. 60 days or more) might be justified and would increase the bioconversion efficiency.

Little comparison can be made between the digestion of Gracilaria and other seaweeds due to a paucity of research in this area. Preliminary studies indicate that Gracilaria may not be as readily digested as some other seaweeds, particularly chlorophytes (Hanisak, unpublished data). The rates measured for Gracilaria at longer RT's are similar to those reported for the phaeophyte Macrocystis (9), but Gracilaria is considerably less digested at shorter RT's. This reduced digestibility is probably a function of differences in experimental conditions and the greater resistance of the agar in Gracilaria to microbial breakdown.

Gracilaria has been proposed as a possible "energy crop" (1,2). It is now technically feasible to cultivate this species in an aquaculture system for this purpose, but this is probably not economical to do without considering the value of its agar, which is worth far more than the methane produced from its biomass (Hanisak, in preparation). Since, at a 30 day RT, little of the agar is digested, it could be extracted before or after the Gracilaria is loaded into the digester. Under these conditions, both agar and methane could be extracted with little reduction in yield for either product. The energy derived from the methane could be used in processing agar or in cultivating the agarophyte.

Aquaculture is a new, energy-intensive industry that will be developed only if its energy needs can be met at a reasonable cost. Seaweeds, grown as part of an aquaculture system, can serve as an alternative energy source and replace the need for conventional fossil fuels. Any energy conserved in this manner would, of course, reduce overall energy demands. Thus, the use of seaweeds as an "energy crop", may play a role as part of man's solution to the present energy crisis.

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