Feasibility of seaweed and agricultural crop waste residues as co-digestion feedstock

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Abstract
This research aims to investigate the feasibility of wild and cultivated brown seaweed species *Saccharina latissima* as a novel feedstock for co-digestion process with agricultural crop waste residues including wheat, corn, grass, and sugarbeet-vegetable mix. Anaerobic digestion of seaweed has been an increasingly important area of research in recent years. Co-digestion of seaweed together with a further waste feedstock is a developing research area. These results indicate that seaweed offers potential as a co-digestion feedstock enhancing overall methane production. This is possibly because seaweed has lower cellulose, no lignin, and high sugar content which aids better digestion performance. Also, seaweed is cultivated in a marine environment, thus it does not compete with food production or potable water, which makes it an attractive biofuel feedstock. However, there are challenges involved for continuous AD operations including large scale cultivation and supply of seaweed, seasonal variability affecting the biochemical composition of seaweed, and the optimum carbon to nitrogen ratio for co-digestion using seaweed.

Keywords
Anaerobic digestion; Seaweed; Co-digestion; Methane; novel feedstock

INTRODUCTION

Huge amount of agricultural biomass is burnt every year in an open field environment that results in the release of harmful gases having a negative impact on the sustainable development of the society [1]. Marine seaweed (macroalgae), due to their higher growth rates, greater productivity and carbon dioxide fixation rates when compared to land crops, and lack of need for arable land and potable water, have been recently focused as an alternative feedstock for renewable energy production including anaerobic digestion (AD). Biomethane potential of the seaweed is highly dependent on chemical composition which varies due to its type, habitat, cultivation method and harvest times [2]. Feeding seaweed into existing wastewater AD plants using co-digestion has been researched recently exhibiting results allowing to overcome the challenges such as low digestion efficiencies, trace element addition, higher salinity levels and accumulation of volatile fatty acids observed while digesting seaweed alone as a single feedstock [3]. Moreover, agricultural crop waste residues and seaweed are distinct from the dedicated energy crops and are available without upstream concerns for energy conversion processes for a bio-refinery concept[4].

Process description

Biochemical Methane Potential (BMP) tests were carried out to determine the gas production potential for the feedstocks as single feedstock and also as co-digestion feedstocks. The tests were run for 30 days. The tests were run separately for the wild and cultivated seaweed samples.

MATERIALS AND METHODS

Seaweed was kindly donated by Marine Laboratories, Queen's University Belfast. Both wild and cultivated samples were received during the summer harvest in June 2016. The agricultural crop waste feedstocks were collected from Vale Green Energy Ltd., UK and BSG from The Froth Blowers Ltd. brewery in Birmingham. Seaweed was macerated prior to the tests. The biochemical methane potential tests were performed using the automated methane potential testing system (AMPTSII). The characterisation results of the feedstock tested for BMP are given below in Table 1 and 2. The feedstock are tested for their total solids (TS), volatile solids (VS), ash content, VS (%TS), elemental composition and calorific values (CV).

Lab-scale continuous experiment

The lab scale trials were conducted using equipment from Bioprocess Control AB, Sweden. This comprised 14 continuous 2 litre glass anaerobic digester reactors, each with a 500 mL CO_2 scrubbing unit, and a biogas volume measuring device. Biogas production was monitored online and the reports from the end of every BMP test was analysed for the specific methane production for each single feedstock and co-digestion combination.

RESULTS AND DISCUSSION

Feedstock Characterisation

Table 1 shows the characterisation of the feedstock in terms of its solids content, calorific values, and ash content. Table 2 shows the elemental composition of the feedstock. Characteristics of wild and cultivated seaweed samples are shown separately.

Table 1. Characterisation of feedstock *W – Wild; C – Cultivated

Feedstock	TS (%WW)	VS (%WW)	CV (MJ/KG)	Ash (%WW)	VS (%TS)
Pig Manure	90.04	58.77	12.38	31.27	65
Brewery Spent Grain	25.91	25.11	14.85	0.80	97
Wheat	86.37	84.60	16.70	1.77	97
Corn	34.62	32.86	16.99	1.75	94
Grass	38.05	34.06	16.93	3.99	89
Sugarbeet-Vegetable waste Mix	25.8	22.52	15.39	3.35	86
S.latissima $_W$.	25.97	17.84	9.7	1.86	69
S.latissima $_C$.	17.04	11.29	11.1	5.74	66
S. latissima $_W$ + *W*heat	72.24	68.99	-	8.45	96
S. latissima $_W$ + Corn	29.10	25.57	-	4.02	88
S. latissima $_W$ + Grass	31.59	26.56	-	2.30	84
S. latissima $_W$ + Sugarbeet-Vegetable waste Mix	27.85	20.51	- -	3.32	74
S. *latissima* $_W$ + Pigmanure	67.23	44.44	-	8.30	66
S. *latissima* $_W$ + BSG	30.16	27.52	-	3.05	91
S. latissima $_C$ + *W*heat	66.05	62.79	-	3.25	95
S. latissima $_C$ + Corn	29.38	26.55	-	2.84	90
S. latissima $_C$ + Grass	31.45	27.18	-	4.27	86
S. latissima $_C$ + Sugarbeet-Vegetable waste Mix	23.21	19.16	-	4.04	83
S. *latissima* $_C$ + Pigmanure	66.49	43.71	-	22.78	65
S. *latissima* $_C$ + BSG	27.75	25.10	-	2.65	90

Table 2. Elemental Composition of feedstock

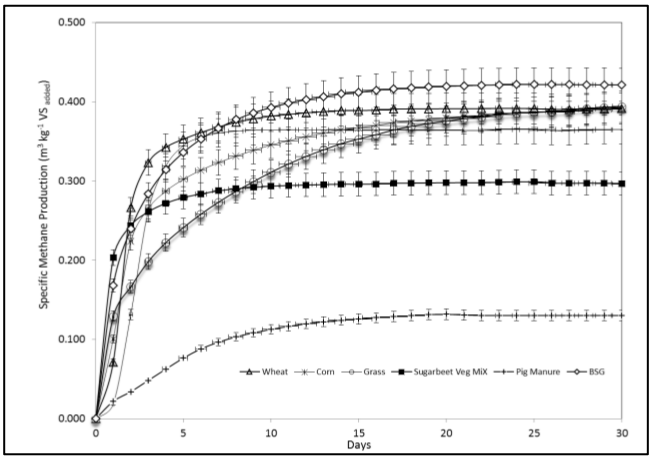
Feedstock	C (%WW)	H (%WW)	N (%WW)	O (%WW)	S (%WW)
Pig Manure	29	2	3	27	1
BSG	35	4	1	39	0.2
Wheat	40	5	2	45	0.14
Corn	43	5	1	40	0.07
Grass	42	4	1	38	0.13
Sugarbeet mix	35	4	1	40	0.07
S.latissima $_{W.}$	30	3	1	34	0.35
S.latissima $_{C.}$	29	3	1	30	0.63

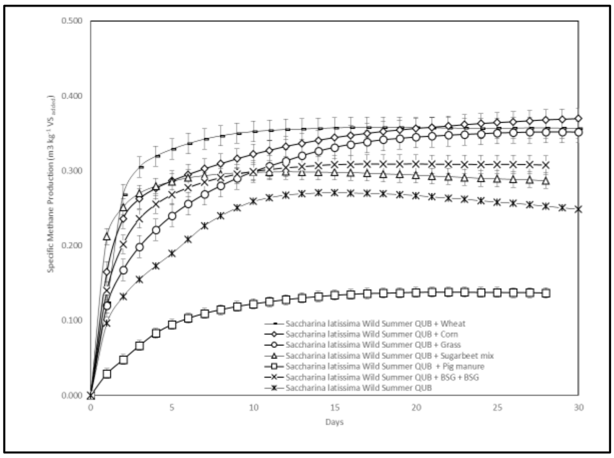
Experimental work (BMP Tests)

Seasonal variation in the chemical composition of brown seaweed species and of *S.latissima* has been recently studied by [5] which highlighted the seasonal variations affecting the best harvest times and its implications for use as a fermentation substrate. There have been studies investigating the effect of carbon to nitrogen ratio, different organic loading rates, and effect of ammonia inhibition during the anaerobic digestion of seaweed [6, 7]. Still there are limited studies undertaken to investigate the co-digestion potential of seaweed with different feedstocks. Co-digestion in general is beneficial for increased biogas production and reduced toxicity helping to bring nutrient balances in a digester. Co-digestion specifically with the seaweed aids both increased biogas production and also utilising higher organic loading rates compared to mono digestion [8]. Results from the BMP tests for the specific methane production for agricultural crop waste residues, pig manure and brewery spent grain as a single feedstock is shown in Figure 1 and as a co-digestion feedstock is shown in Figure 2. The substrates were mixed in a 30:70 ratio of macerated seaweed:co-digestion feedstock. The tested agricultural crop residues included wheat, corn, grass and sugar beet-vegetable mix. *S. latissima* as a single feedstock had a methane production of 0.393 l CH_4 kg^{-1}VS for the cultivated sample and 0.249 l CH_4 kg^{-1}VS for the wild samples. The waste feedstocks had a methane production of 0.421 (BSG), 0.391 (wheat), 0.393 (corn), 0.391 (Grass), 0.291 (sugar beet mix), 0.130 l CH_4 kg^{-1}VS (pig manure) respectively. On co-digestion trials, wild seaweed and corn had a methane production of 0.370 l CH_4 kg^{-1}VS, 0.357 (seaweed and wheat), 0.352 (seaweed and grass), 0.284 (seaweed and sugar beet mix), 0.136 (seaweed and pig manure) and 0.306 l CH_4 kg^{-1}VS (seaweed and BSG) respectively. With cultivated samples, wheat had the highest specific methane production of 0.414 l CH_4 kg^{-1}VS, followed by corn 0.352 l CH_4 kg^{-1}VS, 0.315 l CH_4 kg^{-1}VS(seaweed and grass), 0.285 l CH_4 kg^{-1}VS(seaweed and sugarbeet mix), 0.288 l CH_4 kg^{-1}VS (seaweed and BSG) and 0.196 l CH_4 kg^{-1}VS (seaweed and pigmanure) respectively. As a single feedstock and as a co-digestion feedstock with agricultural crop waste feedstocks, seaweed *S. latissima* is found to be feasible for methane production. Wheat is found to be the best performing feedstock and sugar beet-vegetable mix is found to be the least methane producing feedstock among the agricultural crop waste residues. The results obtained with the wheat residues in the current study is even higher than the previous studies of seaweed with wheat straw [9]. It is observed that cultivated samples have better methane production potential than the wild samples which also makes it essential to optimise the cultivation methods for seaweed. Semi-continuous digestion trials are currently performed to monitor the performance of the feedstocks in a more detailed manner.

Implications for full scale trials

In Ireland, five kelp species dominate the seaweed biomass and feasibility studies have been conducted to recommend *S. latissima* among Laminaria digitata, Laminaria hyperborea, Sacchorhiza polyschides and Alaria esculenta for anaerobic digestion [10]. *S. latissima*, the brown kelp has a structure without midrib and short stipe, longer fronds, and cell walls with mannitol and alginic acid and no lignocellulose which makes it easily digested anaerobically [5]. As shown in this study, *S.latissima* also has lower protein content which makes it feasible to use it in combination with other feedstocks. However seaweed has the growth during winter and normally harvested in summer. So the seasonal supply of seaweed can be an issue for continuous digestion operations. Also the presence of ash which mainly consists of sodium, potassium, calcium ions and chloride and sulphate as counter ions can be potential inhibitors to anaerobic digestion [5, 7].





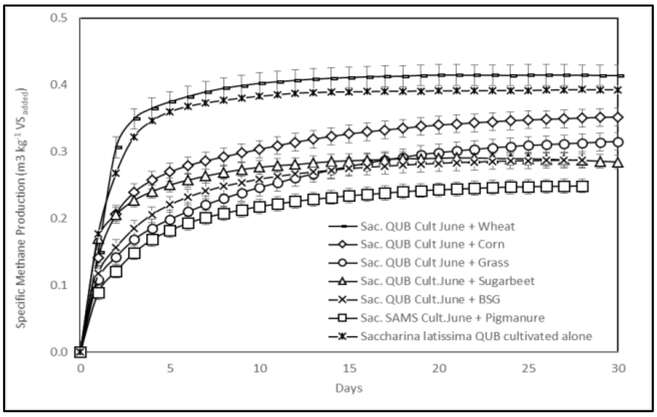


Figure 1. Specific methane production of co-digestion feedstock alone**, Fig 2.**Methane Production of co-digestion of *S. Latissima Wild* with waste feedstocks **Fig 3.** Methane Production of co-digestion of *S. Latissima Cultivated* with waste feedstocks

CONCLUSIONS

Irish brown seaweeds have been studied in detail for their seasonal biochemical composition characteristics affecting its anaerobic digestion performance. However very limited research is done to date detailing their co-digestion potential with waste feedstocks. This research investigated the anaerobic co-digestion potential of summer harvested Irish seaweed species *S. latissima*. The tests demonstrated that the cultivated seaweed species *S. latissima* has a potential for enhancing the overall methane production while co-digested with the various tested waste feedstocks. This research shows that seaweed is amenable to co-digestion with agricultural crop waste residues, brewery spent grain and pig manure and is suitable for biogas production. Hence *S. latissima* is suggested as a feasible novel feedstock for co-digestion.

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