Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 14, No. 4, December , (2018)
P.P. 83- 91

Co-digestion of Shumblan with Different Wastes as a Source for the Biogas Production

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(Received 13 March 2018; accepted 30 April 2018)
https://doi.org/10.22153/kej.2018.04.004

Abstract

Shumblan (SH) is one of the most undesirable aquatic plants widespread in the irrigation channels and water bodies. This work focuses on boosting the biogas potential of shumblan by co-digesting it with other types of wastes without employing any chemical or thermal pretreatments as done in previous studies. A maximum biogas recovery of 378 ml/g VS was reached using shumblan with cow manure as inoculum in a ratio of 1:1. The methane content of the biogas was 55%. Based on volatile solid (VS) and C/N ratios, biogas productions of 518, 434, and 580 ml/g VS were obtained when the shumblan was co-digested with food wastes (SH:F), paper wastes (SH:P), and green wastes (SH:G) respectively. No significant changes of methane contents were observed during the anaerobic co-digestion of shumblan with the selected wastes. This noticeable increments of biogas yields proved that this sort of biomass can be utilized as a promising source for bioenergy production of industrial scale because of its economic operation. Slight pH variations indicated that the co-digestion performance has a good stability operation and no excessive amounts of volatile fatty acid were accumulated. The results also proved that by using co-digestion technology, the biodegradation of shumblan plants could be significantly accelerated supplying greater amounts of biogas yields. Moreover, the appropriate co-digestion with other wastes gave the shumblan high digestibility and, hence, there will be no need to prior pretreatment in order to boost the biogas yield.

Keyword: *Aquatic macrophytes, shumblan biomass, anaerobic co-digestion, biogas.*

1. Introduction

Aquatic plants (Cerathophyllum demersum) are one of the biggest challenges facing aquatic life and causing stress freshwater around the irrigation channels. However, the uncontrolled and rapid growth of aquatic plants has also caused other environmental dangers such as foul odor, interference with navigation, deoxygenation of water, water stagnation and increasing mosquito breeding sites [1]. Shumblan, as it known in the Middle East area, is one of these unwanted plants, which comprise floating, emergent, and submerged aquatic macrophytes. To solve the slow degradation of cellulose and lignin, most previous studies used high ratios of inoculums in order to provide optimum conditions for the successful operation of anaerobic digestion [2-4]. More extended research activities have been carried out using chemical or thermal pre-treatments processes to accelerate the hydrolysis of lignin, which in turn leads to improve the anaerobic digestion conditions toward increase the biomethane yield [5-11]. Due to their high content of cellulose and lignin, few researchers have investigated the use of shumblan toward bioenergy production. Nonetheless, the literature has recognized several key factors in the biochemical composition of algal biomass affecting biogas production, such as moisture content, ash content, lignin, fraction lipids, carbohydrates and proteins [12]. Laura et al. [13] studied the energy recovery from macro-algae (*C.demersum*) using anaerobic digestion process. Her research exhibited that the methane yield was 554 ml CH_4/gm VS. In general, the range of aquatic biomass yield is wide, starting from 100 to 500 ml CH_4/gm VS, if this biomass yields methane more than 400 – 450 ml CH_4/gm VS it provided a high yield and could be viable for industrial use. Anaerobic co-digestion may be capable to be a successful alternative for increasing the biodegradability of the macrophytes, which can, in turn, increase the biogas production. Co-digestion of shumblan with other wastes gave a more optimal substrate mix in this regard, however, interestingly, a stable process was observed even with a C/N ratio within the range of 20-30 [14]. For adjusting C/N ratio, Zehan et al. [15] used activated sludge as a co-waste in co-digestion with macrophytes biomass. However, No study has investigated the potential of the co-digestion of macrophytes biomass with other types of co-substrates such as food, green or paper wastes.

This study explored an alternative way to employ anaerobic digestion of shumblan biomass without chemical or thermal pretreatments and could be feasible to the bioenergy plant operation. By using appropriate alternative technology, co-digestion of aquatic macrophytes biomasses with other wastes maybe presented a promising method for reducing effectively the operation cost and increasing the volumetric biogas yield, Based on volatile solid concentrations and C/N ratios. The selected wastes for co-digestion with shumblan were food waste, paper waste, and green waste as well as the cow manure as inoculum.

2. Materials and Methods

2.1 Feedstock and Inoculum

Free-floating shumblan plants were harvested locally from irrigation channels in the University of Baghdad. The collected species were dried in the sun for two weeks to obtain biomass products for the proposed biogas batch experiments. Then, the biomasses of shumblan were shredded using electric blender up the sizes of particles of 5 mm were formed by using molecular sieve. Based on the volatile solid and C/N ratios, food wastes, paper wastes, and green wastes were added to the shumblan and compared their biogas output with that yield from the shumblan alone. As inoculum, cow manure was blended with the feedstock in a ratio of 1:1 (based on VS). It was used in its dry state after 7 days of storage at 30°C to minimize its content of biodegradable materials that probably influences the biogas results [16]. Total solid (TS) and volatile solid (VS) were determined according to the standard method AOAC 2000 [17] and C/N contents were measured by element analyzer equipment (Table.1).

Table1,
characteristics of the used wastes

Sample	Symbol	TS%	VS%	VS/TS%	C/N
shumblan biomass	SH	83.6	49.9	59.68	14
food waste	F	31	27.2	87.7	24
green waste	G	19	15	78.95	25
paper waste	P	92.2	79	85.7	136
cow manure	CW	32	23	72	16

To accelerate the degradation of shumblan, designed and recommended loadings of shumblan with the other wastes that were mixed for anaerobic co-digestion were reported in Table.2. Loading rates of high and low volatile solid concentrations were treated taking into account the adjusted C/N values. As stated earlier, the same ratios of cow manure were blended to the co-digested substrates as shown in Table.2.

Table2,
mixing ratios of co-digestion of shumblan.

Sample	Mixing ratio	VS (gm/L)	Cow manure VSgm /L	C/N
SH:F	1:1	6.5	6.5	22.02
SH:F	5:1	15.6	15.6	17.81
SH:P	2:1	6.5	6.5	21.67
SH:P	3:1	20.8	20.8	19.97
SH:G	1:2	6.5	6.5	19.17

2.3 Experimental Design

As shown in the Figure. 1, 500 ml batch reactors were used as batch digesters to carry out the anaerobic digestion tests under mesophilic conditions. After blending the required amounts of inoculum and substrate, each digester was filled with water up to 400 mL and was labeled with its composition. Then the digesters were purged with nitrogen gas for 5 min to provide the anaerobic condition before it was tightly closed with their covers. The digesters were conducted at 40ºC using a water bath shaker in a constant vibration rate of 80 rpm. Biogas measurement was carried out using water displacement method (Fig.2). The pH value of each digester was recorded before and after each experiment with a pH meter (WTW Co., Germany, INOLAB 7110). All the samples were duplicate and the results given were mean values. To measure the methane content in the generated biogas, gas analyzer was used (biogas5000, England, G502483).

Fig. 1. used digesters in this work.

Fig. 2. biogas volumetric measurement device.

3. Results and Discussion
3.1 Anaerobic Digestion of the Shumblan

The results of biogas yield for three different volatile solid concentrations of shumblan biomass are shown in Fig.3. The results showed that the SH at VS concentration of 6.5, 25, and 50 (gm/L) generated cumulative biogas of 378, 277, and 170, respectively. That is, the lower the volatile solids, the greater the biogas production. These results confirm that shumblan can be a feasible source for biogas extraction when a proper volatile solid concentration was used. After 15 days of digestion time, a significant increase in biogas rate from shumblan was observed due to its compositions of lignocellulose and lignin that needed a longer time to degrade completely [18]. However, it was observed that the generation of biogas was mostly completed in range between 70 and 90 days. This difference in digestion time can also be attributed to the lower water content, which is necessary for the microorganisms to break down the cellulose and lignin into small soluble materials [19]. This result (378 ml/gmVS) was slightly lower than 417 ml/gmVS obtained with macrophytes algae by Pugliese et al. [20]. Pastare et al. [21] reported higher biogas production (471 mlCH_4/gmVS) with higher C.demersum/inoculum ratio of 1:10. This high biogas produced may be due to a higher amount of inoculum [21]. Thus, using different C.demersum/inoculum ratios led to a significant variance of biogas production, since the kinetic behavior of the inoculum was different with the higher concentration presented in the substrate. Table 3 shows the results of pH values and methane composition for each sample. It was found that the values of pH were not changed significantly before and after each digestion process. This indicated that there was no accumulation of excess volatile fatty acid (VFA). Moreover, this stability of pH during the digestion process provided an excellent environment for methanogenic bacteria performance. Table 3 also demonstrated that the composition of methane content ranged between 55 to 64 %. The highest methane content was not synchronized with highest biogas production. The highest methane composition was generated with highest VS content. This can be attributed to the excess formation of acetate, which is main source for methane production.

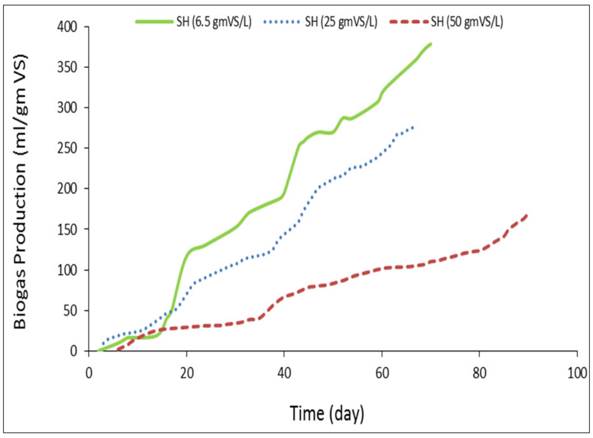

Fig. 3. accumulative biogas production of three different concentrations of shumblan.

Table 3,
pH values and methane compositions of shumblan

SH (gm VS/L)	pH_i	pH_f	CH_4 %
6.5	8	8.5	55
25	7.5	7.24	54.4
50	8	7.58	64

3.2 Anaerobic Digestion of the Additive Wastes

The results of the biogas production for food, green, and paper wastes were curved in Fig. 4.3 together with shumblan for comparison. All experiments were run at a VS concentration of 6.5 gm/L. A maximum biogas production was at the food waste after 41 days (1070 ml/gmVS); this was due to the larger water soluble materials (sugars, proteins, lipids) rathere than complex compounds (cellulose and lignin). However, the food waste digester started the biogas generation on the 4th day of the digestion time. On the 26th day, there was a sharp increase in the biogas production rate, indicating that an increase in the activities of the methanogenic bacteria. Green and paper wastes delivered biogas rates of 333 and 97 ml/gmVS after a digestion time of 61 and 70 days, respectively. Green wastes showed a slightly lower cumulative biogas production to that of shumblan. In contrast, the biogas released from paper wastes proved lower results than those of the other substrates. Paper waste had less biogas productivity because paper waste containing cellulose, hemicellulose, pectin and lignin are very difficult to biodegradable and their hydrolysis step takes longer time [22]. It was noted that the paper waste released a significant biogas rate after 33 days of the digestion time. Hence, the hydrolysis step is often considered as the rate-limiting step when utilizing these kinds of substrates [23]. Although shumblan wastes contain lignocellulose material, as it exists in the green and paper wastes, the productivity of its biogas also was higher during the same period.

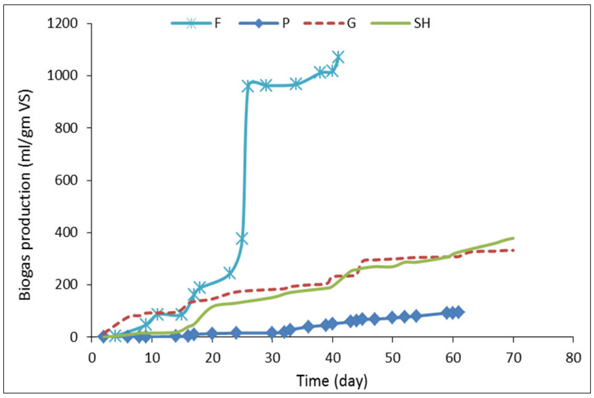

Fig. 4 accumulative biogas production for food, paper, green and shumblan wastes

This result can be attributed to the higher content of lipids and rich nutrients such as carbon, nitrogen and phosphorus, which are essential nutrients for anaerobic microorganisms [24].

Methane content and pH values for each waste are listed in Table 4. It can be seen that the food waste have highest percent of methane followed by that of green, shumblan, and paper wastes. This is because; the quality of the biogas depends on several parameters such as the composition of the treated waste, C/N ratio, and the lignin content [25]. In general, food waste has larger water soluble materials such as sugar, proteins, and fats than those available in the materials of the origin plant. Consequently, the biodegradation of the organic wastes would be shifted toward acetic acid formation rather than toward generation of CO_2 and H_2 gases during acetogensis stage [17]. As in the case of shumblan, pH_i and pH_f values were kept in a slight differences, indicating that the anaerobic digestion was performed under stable conditions.

Table 4,
pH and methane composition values of used substrates

Sample	gm VS/L	pH_i	pH_f	CH_4 %
F	6.5	8	8	70
P	6.5	7.5	7	50
G	6.5	7.5	7	56.5
SH	6.5	8	8.5	55

3.3 Co-digestion of the shumblan with food wastes

The results of the co-digestion of shumblan with food waste are depicted in Fig.5. Accumulative biogas productions from SH:F substrates with 1:1 (6.5 gmVS/L) and 5:1 (15.6 gmVS/L) mixing ratios were 518 and 77 ml/gmVS, respectively. Unexpected divergence in rates of biogas production were observed for both SH:F mixtures. Compared with the digestion of SH alone, the biogas yield from SH:F (1:1) was higher by 36% . As for the SH:F (5:1), the biogas yield was less by 86%. Although the high volatile solid content of SH:F mixture shows a lower biogas yield, the presence of excess lignocelluloses and lignin can significantly affect the anaerobic digestion of the SH biomass. On the other hand, adjusting C/N ratios resulted in an increase in biogas yield from SH:F (1:1) compared to SH alone which indicated a higher microorganism activates was performed. However, there was no significant change in pH values indicating that no excess amounts of fatty acids were formed during acidogensis step (Table.5). As for the digestion time, the results show that both two mixtures needed lower time compared to shumblan. The fast hydrolysis step for the SH:F (1:1) sample and the low water content for the SH:F (5:1) sample was the main reason for this variable digestion time. Table. 5 showed that in all the experiments the methane content was between 53-56% of the total biogas released. These values were lower than obtained by the digestion of food waste alone and close to that obtained by the shumblan alone. This may be attributed of releasing additive gases (CO_2, NH_3 and H_2S) during the digestion process when the shumblan had co-digested with the food wastes. Koyama *et al.* [26] reported that in co-digestion experiment of submerged microphyted and food wastes, more biogas released as the food wastes increased. Under various macrophyte to food waste ratios, he demonstrated that the addition of the food waste dropped pH of the sample, which provided better conditions for the digestion process, but at the same time food waste is inhibited due to the release of dissolved lignin. Krustok *et al.* [27] established a co-digestion experiment for microalgae with food waste. They showed that replacement of 12% food wastes with microalgae released biogas higher than the proportion of 25 and 37%. This decrease could be caused due to the consumption of food wastes as bacteria feed at the same time the algal biomass converted to biogas.

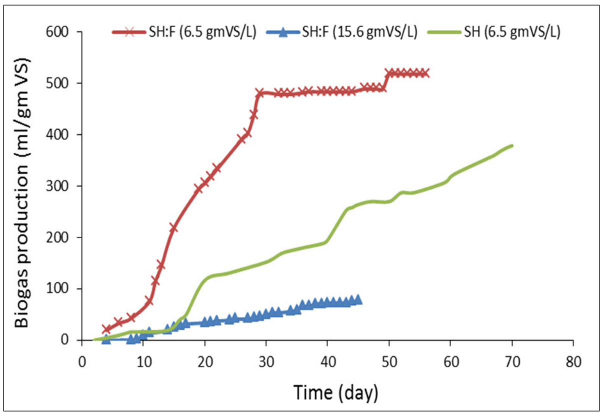

Fig. 5. accumulative biogas production from SH:F substrates

Table 5,
pH values of SH:F substrates

Sample	Wt. of VS	pH_i	pH_f	CH_4%
SH:F (1:1)	6.5	7.2	7.93	53
SH:F (5:1)	15.6	7.02	7.63	56

3.4 Co-digestion of the Shumblan with Paper Wastes

The biogas yields during the co-digestion of the shumblan with paper waste are shown in Fig.6. Accumulative biogas productions from SH:P substrates with 2:1 (6.5 gmVS/L) and 3:1 (20.8 gmVS/L) mixing ratios were 434 and 158 ml/gmVS, respectively. Both SH:P (2:1) and SH biomass showed comparable behavior of biogas yield during the first 18 days of digestion time, but less for SH:P (3:1). At the end of the digestion, the biodegradability of SH:P (2:1) increased by 15% than that of the shumblan at the same concentration of the volatile solid (6.5 gm/L). SH:P (3:1) released biogas yield less by 74% than that of the shumblan. This variance in biogas yield can be attributed to the high cellulose materials in paper wastes, which need high amounts of water to degrade them. This demonstrates that the use of the high-level amount of the paper wastes affected the biogas production in spite of adjusting its C/N ratio. Moreover, it is concluded that it is difficult to optimize the biogas production from the shumblan biomass depending on the C/N ratio alone. Digestion time results show that less time is required for the SH:P 2:1 (56 days) compared with shumblan (70 days) due to the best adjusting of its C/N ratio. For the case of the SH:P (3:1), it can be seen that longer time (90 days) is still required because of the slow hydrolysis step. pH values were not changed significantly confirming the stability of the co-digestion operation when the paper waste was added to the shumblan (Table. 6). A slight decrease of methane content was observed in released biogas for both SH:P substrates compared with SH, indicating that the methanogenic bacteria are most likely inhibited due to the formation of ammonia [17]. The average methane contents of the biogas yield from SH:P at the two 2:1 and 3:1 were 51% and 49%, respectively. This lower methane content of the SH:P indicated that there was an inhibition to methanogenic microorganisms. No literature surveys are available to compare the result of this study with them.

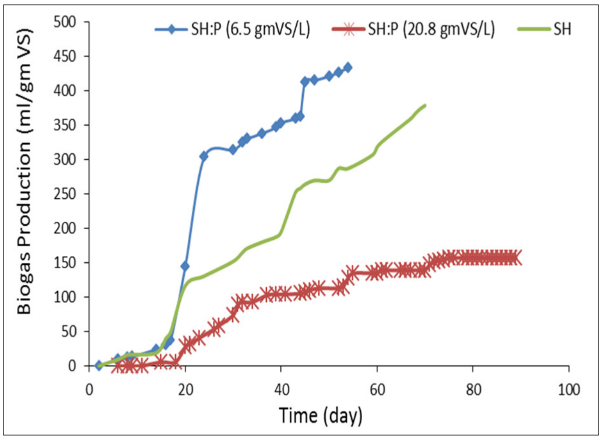

Fig. 6. accumulative biogas production from SH:P substrates

Table 6,
pH values of SH:P substrates

Sample	Wt. of VS	pH_i	pH_f	CH_4 %
SH:P (2:1)	6.5	7	8	51
SH:P (3:1)	20.8	7	7.99	49

3.5 Co-digestion of the shumblan with green wastes

Fig. 7 shows the results of biogas yield rates for the co-digestion shumblan with green wastes (SH:G). It can be seen that the biogas production of SH:G (2:1) substrate rapidly released from day 2. Higher biogas production rate with SH:G substrate was observed probably because green waste is more easily degradable than the shumblan. After 70 days of digestion time, the biogas yield of SH:G was 580 gmVS/L, which were remarkably higher by 53% than that from the shumblan alone, confirming this co-substrate (green waste) is highly applicable for the co-digestion with shumblan. Koyama *et al.* [28] reported that the intracellular soluble organic matters (e.g.cytosols) exist in the cell wall of lignocellulosic materials maybe responsible for this increase in the biogas yield. However, adjusting C/N ratio provided a better nutrients source for the microorganisms to be more active for the biogas recovery. The biogas yield of SH:G was relatively high as compared with the other substrates. The pH values before and after the digestion process remained almost constant between 7 and 7.5 indicating the stability of the digestion operation and this little increase in pH value can be attributed to the release of ammonia. In this work, all experiments showed a slight increase of pH between 7 and 8 because of the increase of ammonia as a result of hydrolysis from shumblan and co-substrates. On the other hand, methane conversion (54%) in this experiment was in a close range to that obtained from the shumblan alone. It is worth to mention that the order of the biogas yield rates can be arranged in the following sequence; SH:G > SH:F > SH:P > SH. This increase in biogas production among these mixtures can be also interpreted due to the variances in VS/TS ratios and to the origin nature of the added substrates. The results of this work obviously show that the addition of food, paper, and green wastes improves the feasibility for anaerobic digestion of the shumblan.

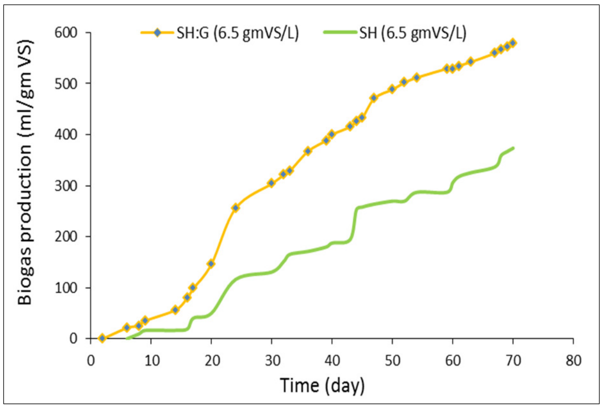

Fig. 7. accumulative biogas production of SH:P and SH

4. Conclusion

The results showed that the addition of food, paper, and green wastes to the shumblan significantly increased the biogas production up to 53% as in the case of SH:G co-digestion. Moreover, anaerobic co-digestion of shumblan could be applicable without the need to use other pre-treatment operations. SH:G has the highest biogas yield followed by that of SH:F and then SH:P. Based on the VS, the biogas yield decreased with increasing the VS concentration. Based on biogas quality, the shumblan waste and its mixtures showed similar results compared to the shumblan alone. The approached constant of pH values for all the co-digestion experiments indicated good stability of these processes. Generally, the study demonstrated that the co-digestion of shumblan and food, paper, and green wastes could be a competitive option for improving the volumetric biogas yield.

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الهضم المشترك (الثنائي) للشمبلان مع النفايات المختلفة كمصدر لإنتاج الغاز الحيوي

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الخلاصة

يعد الشمبلان احد النباتات المائية غير المرغوب فيها المنتشرة في قنوات الري والاجسام المائية. يركز هذا العمل على تعزيز امكانية الغاز الحيوي بوساطة خلط الشمبلان مع انواع مختلفة من المخلفات بدون استعمال اية معالجة كيميائية او حرارية كما في الدراسات السابقة. اعلى قيمة لانتاج الغاز الحيوي باستعمال الشمبلان ملم/غم متطاير ٣٧٨ مع سماد البقر بوصفه لقاحاً بنسبة ١:١. كان محتوى الميثان من الغاز الحيوي ٥٥ ٪ . واستناداً إلى النسب الصلبة المتطايرة و نسبة الكاربون الى النتروجين ، تم الحصول على إنتاج الغاز الحيوي ٥١٨ ، ٤٣٤ ، و ٥٨٠ ملم/غم متطايراً عندما تم خلط الشمبلان مع مخلفات الاطعمة والورق والحشائش ،على التوالي. لم يلاحظ اي تغيير في محتوى الميثان خلال عملية الهضم اللاهوائي المشترك للشمبلان مع المخلفات الاخرى. الزيادات الملحوظة في انتاج الغاز الحيوي اثبتت امكانية استخدام هذا النوع من الكتلة الحيوية بوصفه مصدراً لانتاج الطاقة على النطاق الصناعي بسبب عملها الاقتصادي واشارت التغيرات الطفيفة في قيمة الرقم الهيدوجيني الى ان عملية الهضم اللاهوائي مستقرة جيدا ولم يحصل تراكم للاحماض الامينية. كما اثبتت النتائج الى ان استعمال تقنية الهضم اللاهوائي يؤدي الى تسارع تحلل النبات بشكل كبير ممايؤدي الى زيادة في انتاج الغاز الحيوي . فضلاً عن ذلك، ان الهضم الاهوائي المشترك مع المخلفات الاخرى يعطي للشمبلان قابلية هضم عالية مما يؤدي الى تعزيز في انتاج الغاز الحيوي.