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Effects of chemical compositions and ensiling on the biogas productivity and degradation rates of agricultural and food processing by-products

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HIGHLIGHTS

- Agricultural and food processing by-products (AFPBPs) were used.
- AFPBPs were classified based on their chemical compositions.
- Biogas productivity and degradation rates were determined by biogas potential test.
- AFPBPs showed single- and two-step digestion processes.
- Ensiling of AFPBPs could be promising for biogas production.

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ABSTRACT

The objective of this study was to investigate the effects of chemical compositions and ensiling on the biogas productivity and degradation rates of agricultural and food processing by-products (AFPBPs) using the biogas potential test. The AFPBPs were classified based on their chemical compositions (i.e., carbohydrate, protein and fat contents). The biogas and methane potentials of AFPBPs were calculated to range from 450 to 777 mL/g volatile solids (VS) and 260–543 mL/g VS, respectively. AFPBPs with high fat and protein contents produced significantly higher amounts of biogas than AFPBPs with high carbohydrate and low fat contents. The degradation rate was faster for AFPBPs with high carbohydrate contents compared to AFPBPs with high protein and fat contents. The lag phase and biogas production duration were lower when using ensiled AFPBPs than when using nonsilage AFPBPs. Among the four different silages tested, two silages significantly improved biogas production compared to the nonsilage AFPBPs.

1. Introduction

Anaerobic biodegradation is a process by which complex compounds are degraded into methane, carbon dioxide and other gases by a bacterial consortium. Anaerobic processes are an attractive alternative to aerobic processes for treating low to high strength wastewater and for producing biogas as an energy source. Compared to aerobic treatment systems, anaerobic processes have advantages, such as biogas generation, pathogen removal, less sludge production, lower energy consumption and lower space requirements (Kim and Hyun, 2004). Anaerobic digestion of biodegradable waste may both reduce environmental problems and the consumption of fossil fuels. In addition to producing biogas, an advantage of anaerobic digestion is that it produces a mineralized effluent that can be utilized as a biofertilizer because it has a high nitrogen-phosphorus potash (NPK) concentration (Díaz et al., 2011).

Considering the huge amount of organic wastes such as by-products, food industrial wastes and municipal solid wastes that are produced around the world, energy production from biomass provides a renewable alternative to fossil fuels. Many of these wastes are still unexploited and contribute to environmental pollution in both urban and rural areas. Agricultural and food processing by-product (AFPBP) management is one of the most prominent issues for environmental protection. Anaerobic digestion has been used to treat biodegradable waste and convert it to energy. Most AFPBPs are seasonal, and they may accumulate in quantities larger than needed for immediate use. In addition, AFPBPs have a high moisture content, which causes rapid spoilage, so it is difficult to store AFPBPs for use in the future. Thus, storing AFPBPs is a

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Table 1
Chemical compositions of AFPBPs used in this study.

Feed	TS (%)	TC[a]	CP[a]	EE[a]	CF[a]	NFE[a]	NDF[a]	ADF[a]
Pacific saury fish waste (PSFW)	31.4	14.4	40.3	36.4	-	14.4	–	–
Mackerel fish waste (MFW)	35.6	3.3	48.6	34.3	-	3.3	–	–
Cuttle fish waste (CFW)	38.5	26.2	40.3	26.7	-	26.2	–	–
Bread waste (BW)	67.5	80.0	14.6	1.6	1.1	78.9	–	–
Tofu waste(TW)	12	61.0	24.7	9.8	15.3	45.7	39.7	24.9
Rice bran (RB)	90	49.4	15.8	23.2	14.2	35.2	30.3	13.5
Chinese cabbage waste (CCW)	8	79.9	12.1	1.8	19.4	60.5	38.1	22
Brewery grain waste (BGW)	24	60.4	26.1	9.0	17.1	43.3	62.9	43.6
Apple waste (AW)	17.0	92.8	2.8	2.2	7.3	85.5	–	9.0

TC: total carbohydrates; CP: crude protein; EE: ether extract; NFE: nitrogen free extract; NDF: neutral detergent fiber; ADF: acid detergent fiber.
[a] Units expressed as % TS basis.

Table 2
Chemical compositions of AFPBPs silages.

Silage name	Silage composition	Mixture ratio (%, TS basis)	pH	TS (%)	TC[a]	CP[a]	EE[a]	CF[a]	NFE[a]	NDF[a]	ADF[a]
Fish bread waste silage (FBWS)	Fish waste (FW):bread waste (BW)	80:20	5.02–5.20	34.9	20.2	38.1	33.3	0.1	20.1	0	0
Fish brewery grain waste silage (FBGW)	Fish waste (FW):brewery grain waste(BGW)	40:60	6.95–7.16	26.3	46.2	30.5	17.4	11.8	34.4	43.5	30.2
Fish rice bran silage (FRBS)	Fish waste (FW):rice bran (RB)	60:40	5.64–5.88	40.6	20.5	36	34.1	2.5	18	5.3	2.3
Tofu Chinese cabbage waste silage (TCCWS)	Tofu waste (TW):Chinese cabbage waste (CCW)	74:26	4.11–4.15	11.0	61.9	21.1	8.8	15.5	46.4	32.9	18.4

TC: total carbohydrates; CP: crude protein; EE: ether extract; NFE: nitrogen free extract; NDF: neutral detergent fiber; ADF: acid detergent fiber.
[a] TS basis.

complex problem worldwide. The storage technique should be cheap and environmentally friendly.

Ensiling AFPBPs may be a simple, appropriate method to conserve them for a long period for biogas production (Herrmann et al., 2011; Zubr, 1986). Silage is the fermented product resulting from the anaerobic fermentation of sugars in feed (McDonald et al., 1991). Silage will not deteriorate as long as anaerobic conditions are maintained. Thus, the basic function of making silage is to store and preserve feed for later use with minimal loss of nutritional qualities. When AFPBPs are used for energy production, the ensiling conditions do not necessarily have to be as strictly controlled as with fodder crops (Banemann et al., 2007).

Each AFPBP has its own special characteristics and composition. The biogas potential and degradation rate of different AFPBPs vary widely based on their chemical compositions (i.e., carbohydrate, protein and fat contents) (Buswell and Mueller, 1952; VDI, 2006). Thus, it is essential to investigate the biogas production patterns of different AFPBPs before designing suitable anaerobic treatment plants. To the best of our knowledge, no previous study has examined the effects of chemical compositions and ensiling on anaerobic digestion processes. Therefore, the specific objectives of this study were as follows: (1) to characterize AFPBPs based on chemical compositions, (2) to investigate the effects of chemical compositions and ensiling on the biogas productivity and degradation rates of AFPBPs.

2. Methods

2.1. AFPBPs, AFPBPs silages and inoculum

The fish waste (FW) was obtained from a fish cannery and stored at 4 °C. The brewery grain waste (BGW) was obtained from a beer brewer, rice bran (RB) (without oil extraction) was obtained from rice processing industry, and tofu waste (TW) was obtained from a local tofu company. The bread waste (BW) (bread past its expiration date), apple waste (AW) and Chinese cabbage waste (CCW) was obtained from a market.

Table 3
Basis for AFPBPs and their silage classifications.

	Units	Low	Medium	High
Carbohydrate	%	<50	50–70	>70
Protein	%	<15	15–30	>30
Fat	%	<7.5	7.5–15.0	>15
Water soluble carbohydrates (WSC)	%	<20	20–50	>50
Crude fiber (CF)	%	<10	10.0–20.0	>20
Moisture content (MC)	%	<50	50–70	>70

The silage was prepared by fermenting the feed for 22 days in anaerobic bags (2 L capacity) at 25 °C. Silage preparation was performed in triplicate. The prepared silage from each anaerobic bag was crushed in a blender and a 200 g sample was collected for each test (Kafle et al., 2013).

The anaerobic inoculum was obtained from a working mesophilic lab-scale continuous anaerobic digester. Swine manure was used as feed stock in lab-scale anaerobic digester and it was operated at hydraulic retention time (HRT) of 32 days. Same inoculum was used for all the tests performed in this study.

2.2. Classification of AFPBPs and their silages

The chemical compositions of AFPBPs and their silages are shown in Tables 1 and 2, respectively. AFPBPs and their silages were classified as having low, medium and high chemical contents based on their chemical compositions. The basis for classification of AFPBPs and their silages is shown in Table 3.

2.3. Anaerobic digestion test setup and experimental design

Batch anaerobic digestion tests were carried out in 1.3 L glass bottles (liquid volume 0.8 L). The experimental design to measure the biogas productivity of different AFPBPs and their silages are shown in Table 4. The feed to inoculum (F/I) ratio was maintained at 0.5. The F/I ratio was calculated based on the initial amounts of volatile solids (VS) of the substrate and inoculum.