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Effects of pungency degree on mesophilic anaerobic digestion of kitchen waste

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HIGHLIGHTS

- Influence of pungency degree on degradation properties of kitchen waste is studied.
- Characteristics of digestion kinetics are pungency degree dependent.
- Low pungency degrees are beneficial for promote anaerobic degradability.
- Appropriate pungency degrees for anaerobic digestion of kitchen waste are proposed.

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ABSTRACT

This study investigated the influence of pungency degrees (PDs) on mesophilic anaerobic digestion of kitchen waste (KW). Batch tests were performed to evaluate the methane potential and production rate and the effect of PDs on organics degradation efficiency (in terms of volatile solids, protein and ether extract) at mesophilic temperature. Koch and Drewes model and modified Gompertz model were applied to assess the effects of PDs on the hydrolysis rate constant, biomethane yield rate and lag time. The results revealed that with the increasing contributions of PDs, the methane yield, organics degradation efficiency and hydrolysis rate of KW decreased while the pH values and concentrations of total ammonia nitrogen and free ammonia nitrogen were increased. Additionally, PDs lower than PD3 presented better digestion performance, and according to results of organics degradation and kinetics study, it could be suggested that appropriate range of PD in KW beneficial for AD is PD5–PD4.

1. Introduction

About 40 million tons of kitchen waste (KW) is generated in China each year. High biodegradability and water content make KW suitable for anaerobic digestion (AD) with the concomitant benefit of clean energy production, such as biogas, organic waste reduction and others including environmental protection and public health [1].

Substantive investigations have been conducted on the AD of KW and mainly centered on analyses of the degradation efficiency and kinetics properties, using mono-digestion and co-digestion of KW [2–4]. Factors that may affect biogas production and stability of the AD process are also studied, including the inhibitory effects of AD byproducts (e.g., ammonia nitrogen, sulphide, metals and volatile fatty acids) and the physical and chemical characteristics of the waste (such as particle size, moisture content and nutrient contents and components) [5–8]. Besides, effects of various pretreatment methods, including ultrasonic, thermal, microwave, chemical, electrical and freeze/thaw methods on the organics solubilisation and subsequent AD efficiency have been investigated, such as favouring the hydrolysis step, increasing biogas production and reducing the retention time [9]. Among these methods, thermal treatment is one of the most studied pretreatment methods and has been successfully applied at the industrial scale [10,11].

Regional variations are likely to cause differences in eating habits, leading to different content of organics components, such as protein, carbohydrate and ether extract (EE). The difference on hydrolysis rates and biomethanation potential of these components lead to the variations on the operation stabilisation parameters including pH, alkalinity, volatile fatty acids (VFA), loading

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rates, and biogas production and composition [12,13]. In addition, six chemically related compounds in peppers and chilli, including capsaicin, dihydrocapsaicin, norcapsaicin, nordihydrocapsaicin, homocapsaicin and homodihydrocapsaicin, constitute the capsaicinoids group [14]. Capsaicin and dihydrocapsaicin are the two most abundant components of capsaicinoids in peppers, constituting 90% of the total capsaicinoids [15], and capsaicin content normally determines the commercial quality of peppers [16]. Thus, the pungency degrees (PDs) in KW, caused by peppers and chilli with various cultivars, origins, growing conditions, etc., also vary from regions due to different dietary habits. As for PDs, it is often quantified in scales that range from mild to hot, defined by the amount of capsaicin contained by the Scoville scale [17]. So far, most of previous studies about PDs have focused on analyses of the determination methods, such as High Performance Liquid Chromatography (HPLC), Gas chromatography–mass spectrometry (GC–MS), and specific ultra fast liquid chromatographic (UFLC), among which both HPLC and GC–MS were considered as efficient analysis of the content and type of capsaicinoids, and current application in the fields of medicine, biology, chemistry and industry [18–20]. Moreover, researches about influence of PDs are mainly conducted on functions, utilization on food, pharmaceutical and effects on health, dietary consumption and weight, etc. [21–26].

However, no previous study has investigated the influence of PDs on AD performance of KW, or focused on the detailed degradation properties of organics. Hence, in order to achieve a comprehensive understanding and comparative conclusions on the mechanism analysis of organics degradation and removal efficiency influenced by PDs during AD process of KW, particularly the aim of demonstrating the relevant role played on the performance of the AD process by PDs and providing theoretical basis for engineering application, the objective of this study was to investigate and evaluate the influence of PDs on the methane production, kinetics parameters including methane formation rate, lag time and hydrolysis rate, and organics degradation efficiency. Additionally, the feasible strategies for enhancing the AD of KW by appropriate PDs were suggested.

2. Materials and methods

2.1. KW

Table 1a shows the basic characteristics of KW collected on a weekly basis from a canteen in Tsinghua University that can serve approximately 10,000 students and staff members per meal. After manual sorting in order to remove impurities, such as big bones, plastics and metals, the KW was mixed with a kitchen blender to ensure uniform and representative experimental materials. It was then crushed into particles with an average size of 1–2 mm.

According to the analysis of capsaicin content in 45 kinds of capsicum products using high performance liquid chromatography (HPLC) by Li [27], the capsaicin content ranged from 0.043 to 1.254 mg/g. Capsaicin and dihydrocapsaicin account for about 90% of the total capsaicinoids content, and the concentrations of two main components were determined by high-performance liquid chromatography (HPLC) [20], and the total capsaicinoid content in KW was calculated according to Eq. (1):

$$C = (C_1 + C_2)/90\% \tag{1}$$

where C is total capsaicinoid content, $C1$ is capsaicin content, C_2 is dihydrocapsaicin content, and 90% is the proportion of capsaicin and dihydrocapsaicin in total capsaicinoid materials.

The Scoville Heat Value (SHV) of the KW was obtained from Eq. (2):

$$\text{SHV} = C \times 90\% \times (16.1 \times 10^3) + C \times 10\% \times (9.3 \times 10^3) \tag{2}$$

where the unit of SHV is SHU, C is the total capsaicinoid content (g/kg), 90% is the proportion of capsaicin and dihydrocapsaicin in total capsaicinoid materials, 16.1×10^3 is the conversion coefficient of capsaicin and dihydrocapsaicin concentration between g/kg and SHU, 10% is the proportion of other components in total capsaicinoid materials, and 9.3×10^3 is the conversion coefficient of other capsaicinoid materials concentration between g/kg and SHU.

The conversion relation of PDs and SHV is shown as Eq. (3) [28]:

$$1\ \text{PD} = 150\ \text{SHU} \tag{3}$$

Thus, the influence of following PDs in KW on AD of KW was studied in this study (Table 1b) and the Scoville Heat Units (SHU) were used to represent the PDs in KW.

2.2. Anaerobic digestion

Anaerobic digestion tests were conducted in 500-mL glass bottles at 35 °C in the automatic methane potential test system (AMPTS II), which features automatic sample stirring, acid gas (for example, CO_2 and H_2S) removal system and biomethane yield recording system, to measure the real-time biomethane productivity of KW. The AMPTS II instrument consists of three main units: (a) water bath incubation unit including 15 number 500 mL glass bottles containing the test sample and anaerobic inoculum which are incubated at the set temperature. A mixing rod with slow

Table 1b
Characteristics of PDs in KW used in this study.

PD	PD1	PD2	PD3	PD4	PD5	PD6
Values	1136.1	570.7	286.1	190.9	114.6	71.5
SD[a]	20.1	10.1	5.1	3.4	2.0	1.3

[a] SD: standard deviation.

Table 1a
Characteristics of KW used in this study.

Compositions of KW		Characteristics of the KW	
Parameters	Percentage (%)	Parameters	KW
Cooked bone	2.6 ± 0.2	pH	4.5 ± 0.2
Cooked eggshell	1.3 ± 0.1	Total solids (%)	19.1 ± 1.1
Pasta & rice	27.7 ± 0.6	Volatile solids (%, dry basis)	93.2 ± 1.4
Fruit peeling	20.9 ± 1.0	Carbohydrate (%, wet basis)	11.8 ± 0.4
Cooked vegetable	24.3 ± 0.5	Proteins (%, wet basis)	2.5 ± 0.2
Vegetable peeling	20.0 ± 1.2	Ether extract (%, wet basis)	3.5 ± 0.1
Others	3.2 ± 0.2	Carbon (%, dry basis)	46.1 ± 1.6
		Hydrogen (%, dry basis)	7.0 ± 0.2
		Oxygen (%, dry basis)	37.8 ± 1.6
		Nitrogen (%, dry basis)	3.2 ± 0.4