Laboratory Scale Experiments for Biogas Production from Cassava Tubers

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Abstract: The production of biogas, an alternative source of energy, from starch-rich tubers of cassava plant, was investigated in the laboratory scale using the simple single-state digesters of 5- and 20-liter working volumes. The digesters were fed on a batch basis with the slurry of dry cassava tuber containing the average moisture content of 18%, and operated at ambient temperature (29-31°C) for 30 days. When operating the single-state digester of 5-liter working volume fed with the optimal concentrations of carbon and nitrogen sources, 1.00% (w/v) total solids and 0.04% (w/v) urea, the gas yield of 1.95 liters/day containing the maximum methane content of 67.92% was achieved at 10-day retention time. The fermentation reactions were ceased after 16-day operation. The fermentation volume was then scaled up to 20 liters. The gas yield of 5.50 liters/day containing 55.70% methane was obtained at 10-day retention time. Whereas the methane content of 67.57% and the gas yield of 3.88 liters/day were obtained at 14-day retention time. The fermentation reactions were ceased after 24-day operation. Biogas containing 67% methane content could be achieved from the digestion of cassava tubers using simple single-state digesters.

Keywords: Biogas, Cassava, Cassava Tuber, Methane, Single-state Digester.

1. INTRODUCTION

Biogas, the gas generated from organic digestion under anaerobic conditions by mixed population of microorganisms, is an alternative energy source which has been commenced to be utilized both in rural and industrial areas at least since 1958 [17]. The gas generally composes of methane (55-65%), carbon dioxide (35-45%), nitrogen (0-3%), hydrogen (0-1%), and hydrogen sulfide (0-1%) [11]. The composition of biogas depends on feed materials. Organic waste has been mainly used for the biogas production, and several kinds of waste materials have been reported to be exploited (4, 6, 7, 9, 10, 20). Raw cassava tubers, the cheap and abundant agriculture product in Thailand [12, 13, 14], are initially investigated to be applied as a raw material for the bio-energy production in our previous [2] and this studies. In this study, the maximum production of biogas and methane from the starch-rich tuber is determined in laboratory scale using the simple single-state digesters.

2. MATERIALS AND METHODS

2.1 Preparation of the raw material for biogas production

Fresh cassava tubers were collected from their plantation area in Nakhon Ratchasima Province, Thailand. To obtain the consistency of the raw material for biogas production experiments, dry cassava tubers containing the average moisture content of 18% were prepared by chopping the whole tuber into pieces, dried under sun light over a two-day period, then crushed into small pieces (<0.2 cm^3) using blender (Waring Commercial, U.S.A.). Total solids (TS), volatile solids (VS), ash, and phosphorus contents of the raw material were determined using standard methods [1, 3]. Total carbon and nitrogen contents were also determined using CNS-2000 Elemental Analyzer (Leco Corporation, U.S.A). Starch concentration was basically detected by spectrophotometry at 580 nm absorbance in the soluble form and presence of iodine [8, 14].

2.2 Preparation of seed cultures

Seed cultures were prepared by mixing animal manure and liquid waste collected from the anaerobic pond of the cassava starch production factory in Nakhon Ratchasima Province, then kept in a closed container at room temperature with regular adding a small amount of cassava starch for 3 months before inoculating the biogas production digester.

2.3 Biogas production from cassava tubers

The production of biogas from raw cassava tuber was performed using the simple single-state digesters with working volumes of 5 and 20 liters (L) (Table 1, Fig. 1). The digesters were fed on a batch basis with the slurry of dry cassava tuber containing the average moisture content of 18% and 10% (v/v) of seed cultures. The biogas fermentation was then operated in triplicate at ambient temperature for 30 days.

Table 1 Physical characteristics of 5-L and 20-L working volume digesters

Parameter	5 L	20 L
Digester height (cm)	25.00	35.00
Liquid height (cm)	13.50	41.30
Empty volume (L)	7.50	26.00
Filled volume (L)	5.00	20.00

Since the amount of main nutrients (carbon and nitrogen sources) affects the growth of microorganisms and the production of biogas, the optimal concentrations of TS (carbon source) and nitrogen source added were determined. The high carbon-to-nitrogen ratio (approximately 80:1) of cassava root (dry weight) has been reported [16]. The optimum ratios for the maximum biogas generation have been suggested to be 20-30:1 [15, 19]. In this study, various TS concentrations: 0.25, 0.50, 1.00, 2.00, 4.00, and 8.00% (w/v), were applied to the 5-L reaction volume to obtain the optimum TS content. Then the addition of urea (46% of nitrogen) as a nitrogen source at 0.00, 0.02, 0.03, 0.04, 0.10, and 0.20% (w/v) was investigated.

For stabilizing pH of cassava slurry during the anaerobic digestion, the addition of sodium bicarbonate (0.25%, w/v) was considered whenever the volatile fatty acids-to-alkalinity ratio was greater than 0.8.

The volume of biogas produced in the digester was measured by the displacement of water in the gas holder compartment. The pH of water in this holder was adjusted to 2 to avoid carbon dioxide dissolution [1]. Gas production was measured daily. The composition of biogas collected over water, was analyzed using the Gas Analyser (Shimadzu,

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Class-GC14B, Japan) equipped with a thermal conductivity detector (TCD) and 1-M Porapak Q (80-100 mesh) column. Helium was used as a carrier gas at a flow rate of 25 mL/min. The oven, injector, and detector temperatures were 80, 120, and 120°C respectively.

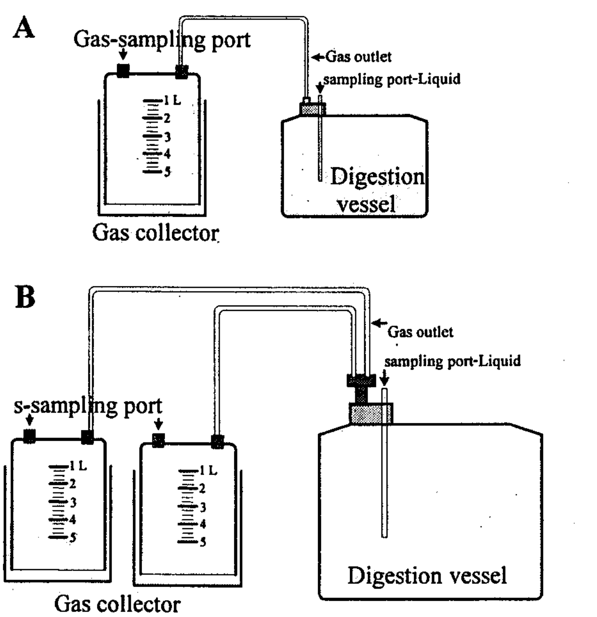


Fig. 1 Single-state digesters of (A) 5-L and (B) 20-L working volumes.

Volatile acids (acetic, propionic, and butyric acids) were analyzed using the Gas Analyser (Shimadzu, Class-GC14B, Japan) equipped with a flame ionization detector (FID) and DB-FFAP column. Helium was used as a carrier gas at a flow rate of 40 cm/sec whereas nitrogen was used as a makeup gas at a flow rate of 30 mL/min. The oven, injector, and detector temperatures were 100, 250, and 300°C, respectively. Peak areas were used to calculate concentrations by comparing to calibration curves prepared from standard solutions of acetic, propionic, and butyric acids.

Starch content, alkalinity, and volatile fatty acids (VFA) of cassava slurry during digestion were determined daily. Alkalinity and VFA were determined by the direct titration with sulfuric acid [1]. The VS content and the reduction of VS in the slurry were detected and calculated [20], respectively. The measurement of pH value and temperature was also performed.

The optimal concentrations of both total solids and nitrogen were applied to produce biogas in the scaled-up digester, 20-L working volume.

3. RESULTS AND DISCUSSION

3.1 Raw material for biogas production

Cassava plant variety KU 50 was one of dominant varieties cultivated in Nakhon Ratchasima Province. Fresh starch-rich tubers of the plant were collected. Some physical and chemical compositions of the tuber were analyzed (Table 2). The fresh tuber has approximately 18% of starch, 62% of moisture, 0.9% of ash, and 0.08% of phosphorus. Soccol (1996) stated that fresh cassava roots had 20-30% of starch, 65% of moisture, 0.9% of ash, and 0.03% of phosphorus [16]. The dry starchy material of variety KU 50 containing 18.65% of moisture, 81.35% of TS, 1.95% of ash, 98.05% of VS, 39.56% of total carbon, 38.10% of starch, 0.46% of total nitrogen, and 0.18% of phosphorus, was used to prepare slurry to feed the simple single-state digesters. The average carbon-to-nitrogen ratio of the dry cassava material is 86:1 which is very high ratio compared to the optimum ratios of 20-30:1 for the maximum biogas generation [15, 19].

Table 2 Compositions of cassava tuber, plant variety KU50, collected from the plantation area in Makhon Ratchasima Province

Composition (%)	Fresh weight	Dry weight
Moisture	61.66	18.65
Total solids (TS)	38.34	81.35
Volatile solids (VS)	99.12	98.05
Total carbon	18.64	39.56
Total nitrogen	0.22	0.46
Starch	17.96	38.10
Ash	0.88	1.95
Phosphorus	0.08	0.18

3.2 Biogas production from cassava tubers

When the single-state digester with working volume of 5 L was used for optimization of some biogas production conditions, the maximum yield of 356.35 L/kg TS fed of biogas was achieved from 1.00% (w/v) TS (Fig. 2). The gas yield of 1.20 liters/day composing the maximum methane content of 64.35% was obtained at 22-day retention time. The fermentation reactions were ceased after operating for 25 days. The volatile solids reduction of fermenting slurry was 39.10%.

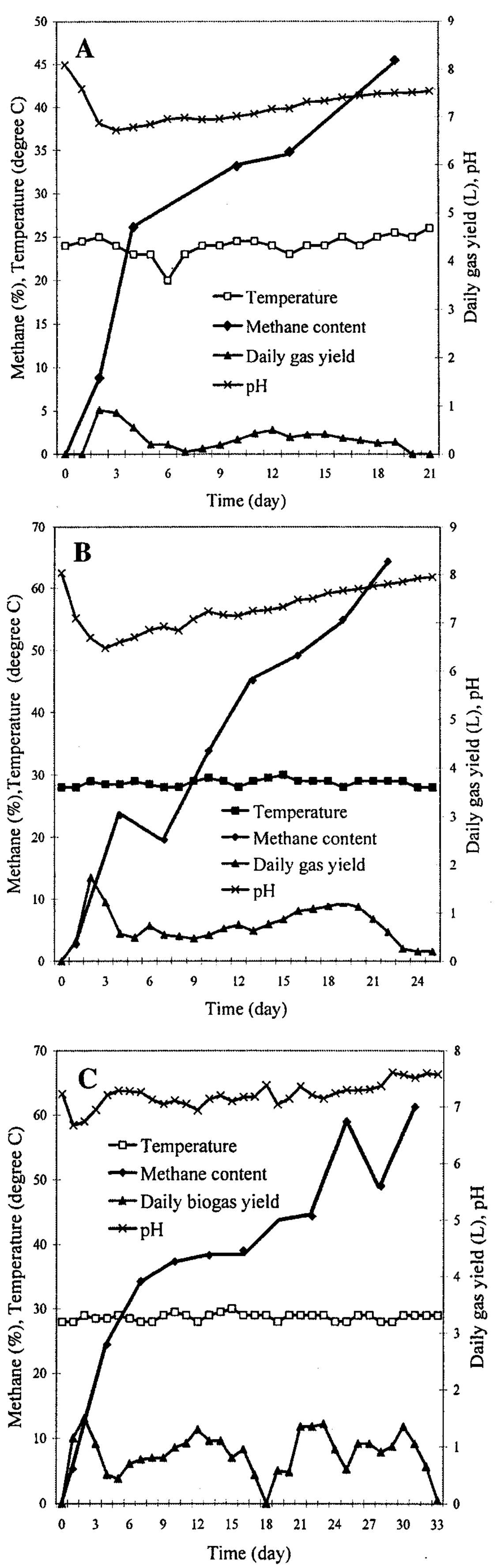
The supplement of urea (0.04%, w/v) to the cassava slurry (1.00%, w/v, TS) could stimulate the maximum biogas production. The maximum yield of total biogas was 569.29 L/kg TS fed. The gas yield of 1.95 liters/day containing the maximum methane content of 67.92% was achieved at 10-day retention time (Figs. 3C, 4A and 5). The utilization of volatile solids was 56.83%. But the fermentation reactions were ceased after 16-day operation (Fig. 4A).

When the optimal concentrations of total solids (1.00%, w/v) and urea 0.04% (w/v) were applied to the scaled-up experiment, 20-L reaction volume, the gas yield of 5.50 liters/day containing 55.70% methane was obtained at 10-day retention time. Whereas the methane content of 67.57% and the gas yield of 3.88 liters/day were obtained at 14-day retention time. The fermentation reactions were ceased after 24-day operation (Figs. 4B and 5).

When the digesters was initially fed, acid forming-bacteria quickly produced acid resulting in declining pH below the neutral pH and diminishing growth of methanogenic bacteria and methanogenesis. The pH could be maintained by adding sodium bicarbonate to increase digester alkalinity. In this study, sodium bicarbonate was added four times during the first week of fermentation for both bioreactor sizes. Afterwards the digesters could maintain themselves (Fig. 4). At the daily methane yield of more than 50% of biogas composition, the digesters operated at a pH range of 7.2 to 7.8 and 7.4 to 8.1 with the alkalinity of 7000-7550 and 6800-9400 mg/L, and VFA of 1585-4218 and 2250-4350 mg/L, for 5-L and 20-L cassava tuber slurry, respectively (Figs. 5 and 6).

Volatile acids (acetic, propionic, and butyric acids) accumulation during cassava tuber fermentation were detected (Fig. 7). The concentration of propionic and butyric acids were higher than that of acetic acid in both digester sizes.

Temperatures of the cassava slurry during fermentation were found to be between 29 and 31°C for all experiments



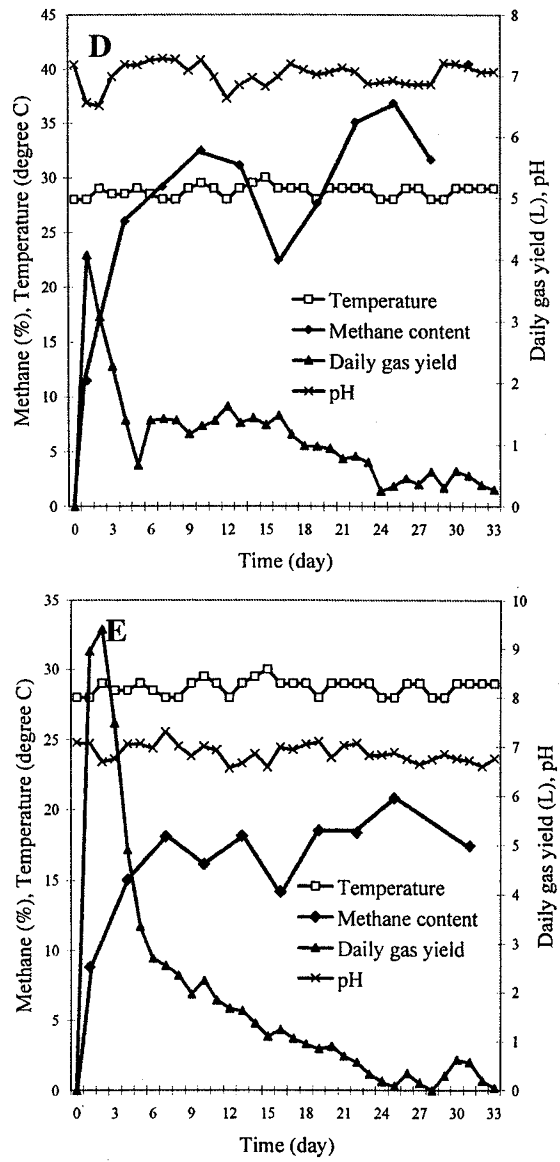
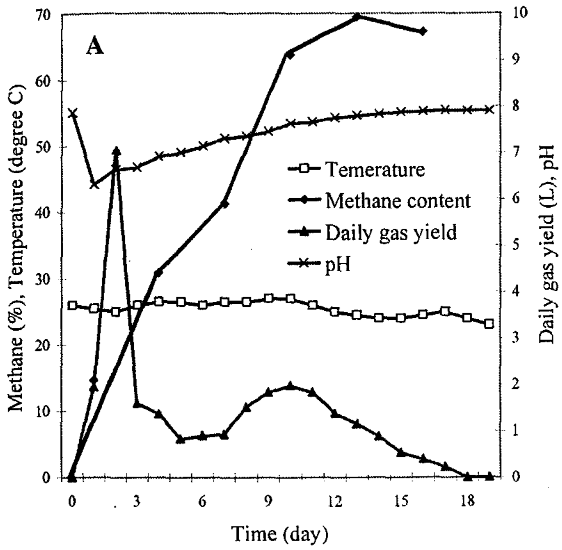


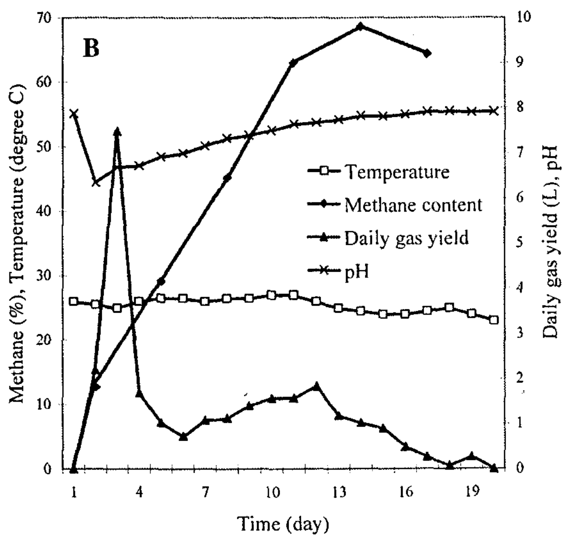
Fig. 2 Biogas production from cassava tubers using (A) 0.50, (B) 1.00, (C) 2.00, (D) 4.00, and (E) 8.00% (w/v) total solids without supplementing a nitrogen source in the single-state digester of 5-L digestion volume.

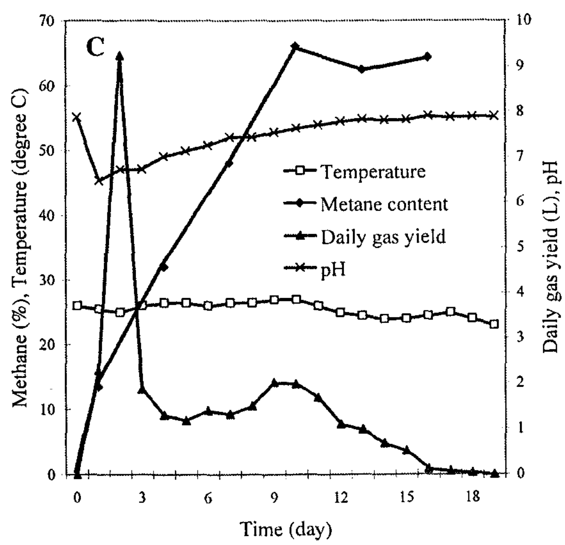
(Fig. 4).

Total biogas yield, total methane yield, and VS reduction obtained from the two bioreactor sizes were compared (Table 3). The total biogas yields of 5-L and 20-L cassava slurry were 569.29 and 611.32 L/kg TS fed respectively. The biogas yield from 20-L working volume was 6.88% higher than the yield from 5 L. The total methane yield was also higher (339.53 L/kg TS fed from 20 L and 263.90 L/kg TS fed from 5 L). But the average methane contents for overall reactions of 5-L and 20-L digestion mixtures were 46.22% and 55.54%, respectively.

The theoretical biogas yield from carbohydrate has been reported to be 886 L/kg VS fed [5]. From our experiments, the total biogas yields per kg VS fed were 474.67 L and 509.71 L from 5-L and 20-L digestion volumes, respectively (Table 3). The obtainable products were lower than theoretical yields.







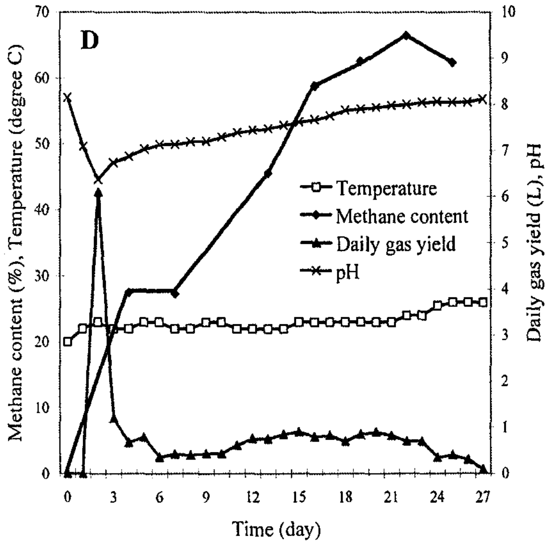


Fig. 3 Biogas production from cassava tubers using 1.00% (w/v) total solids and urea supplements at various concentrations: (A) 0.02, (B) 0.03, (C) 0.04, and (D) 0.10% (w/v), in the single-state digester of 5-L reaction volume.

Table 3 Biogas production from cassava tubers in laboratory scale experiments

Parameter	Reaction volume (L)	
	5	20
Total biogas yield (L/kg TS fed)	569.29	611.32
Total biogas yield (L/kg VS fed)	474.67	509.71
Total methane yield (L/kg TS fed)	263.90	339.53
Volatile solids (VS) reduction (%)	56.83	61.51

4. CONCLUSIONS

Biogas containing the methane content of 67% could be efficiently produced from cassava tuber slurry (1%, w/v, TS) and the supplement of urea (0.04%, w/v) in the simple single-state digester with both 5-L and 20-L reaction volumes. Cassava tubers used to prepared the slurry contain the average contents of 81% of TS, 40% of total carbon, 38% of starch, and 0.5% of total nitrogen. One kilogram (kg) TS of the dry tuber was obtained from 1.23 kg of the total dry mass prepared from the whole tuber. And one kg of the dry cassava mass was achieved from 2.11 kg of fresh cassava tuber. From these practical calculation results, one kg of dry cassava tuber could be biologically converted to 497.01 L of biogas, and one kg of fresh cassava tuber could produce 235.12 L of biogas. If the energy value of biogas (50-70% of methane content) was 22000-26000 kJ/m^3, one kg of fresh and dry cassava tubers used as raw materials for biogas production, could produce 5172.64 kJ and 10934.22 kJ energy, respectively.

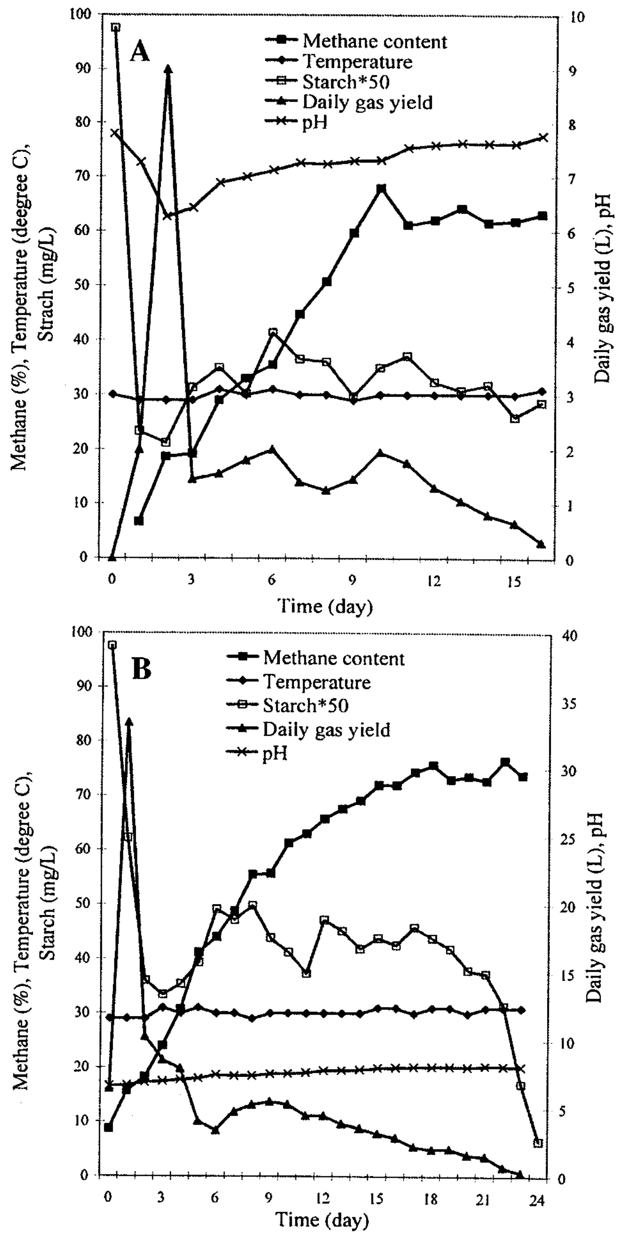


Fig. 4 Biogas production from cassava tubers using 1.00% (w/v) total solids and 0.04% (w/v) urea supplement in the single-state digesters of (A) 5-L and (B) 20-L working volumes.

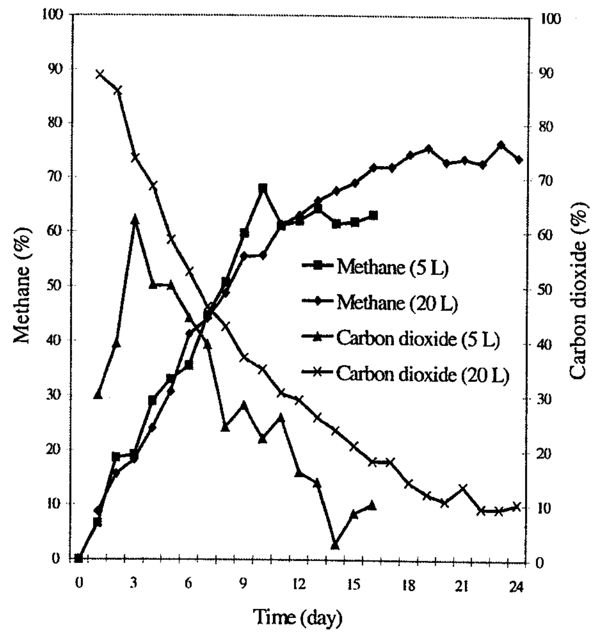


Fig. 5 Methane and carbon dioxide composition of gas measured during cassava tuber fermentation in the single-state digesters of 5-L and 20-L working volumes.

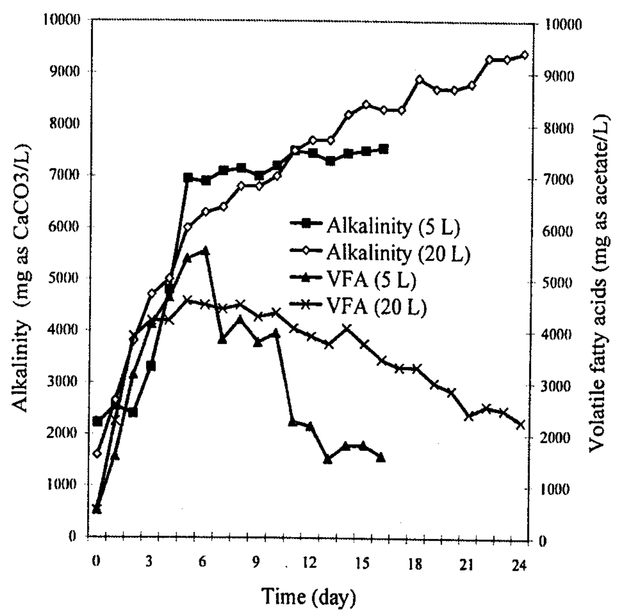


Fig. 6 Alkalinity and volatile fatty acids measured during biogas production from cassava tubers in the single-state digesters of 5-L and 20-L working volumes.

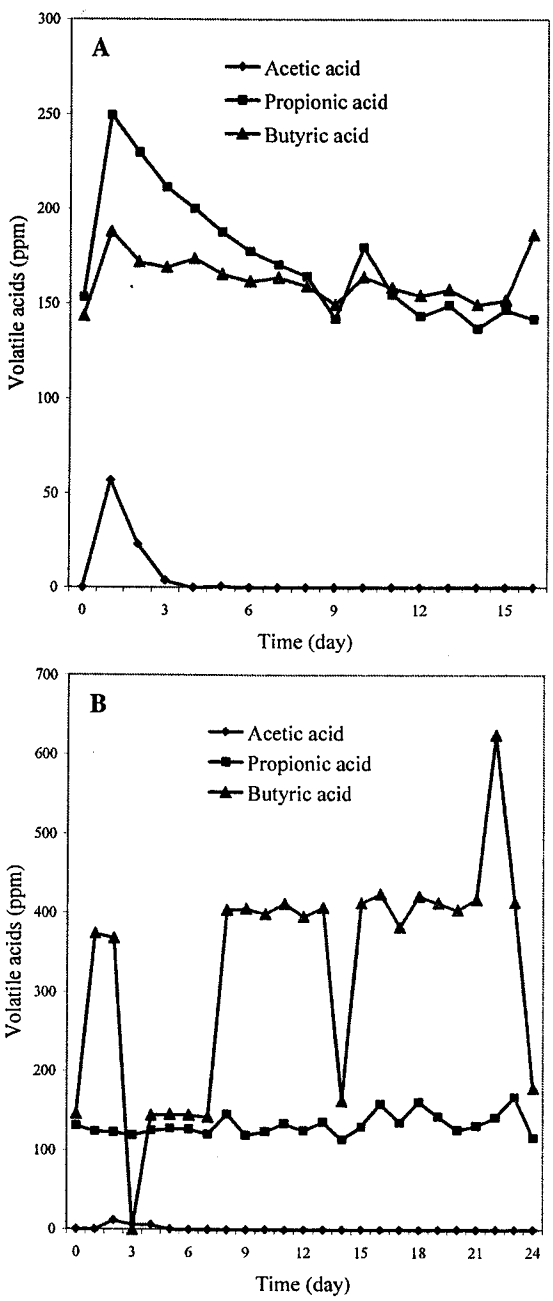


Fig. 7 Volatile acids accumulation during cassava tuber fermentation in the single-state digesters of (A) 5-L and (B) 20-L working volumes.

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