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Full Length Research Paper

Optimization of biogas production from banana peels: Effect of particle size on methane yield

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The *matooke* processing industry being set up by the Presidential Initiative on Banana Industrial Development (PIBID), once fully operational will generate much *matooke* associated waste that requires a sustainable waste handling mechanism. Anaerobic digestion of the peel waste for biogas production would provide a solution to that waste, but information on the pre-treatment of the *matooke* peel waste is inadequate. Hence, a study of the changes in the physicochemical characteristics of *matooke* peels under storage and optimization of particle size for biogas production was sought. Peels from five banana cultivars were analysed after one day, four and seven days of storage at ambient conditions. Peels of one cultivar were reduced to 1, 5 and 10 mm particle sizes and the other four cultivar peels were reduced to 1 mm of particle size. Peel storage pre-treatment of utmost four days was found to bring the carbon to nitrogen (C/N) ratio to the optimal range for anaerobic digestion of 10 to 32. C/N ratio was also found to be cultivar-dependent as it was significant at $\alpha = 0.05$ between the different banana cultivars. A model of methane content depending on particle size was developed. A particle size of 6.73 mm was projected for optimum biogas production, although further validation of this model and optimal particle size is required with a bigger sample.

Key words: Anaerobic digestion, cooking banana cultivars, optimal particle size, peel storage, specific methane yield.

INTRODUCTION

The East African Highland cooking banana (AAA-EA group) commonly called *matooke*, is the leading staple food in Uganda. It is revealed that over 70% of the farmers in Uganda's major producing districts grow banana as a primary crop and over 50% depend on banana for food and cash (Bagambe et al., 2006). Production figure of *matooke* in Uganda is approximately about 6 million tonnes annually (Spilsbury et al., 2002). With this high production of *matooke* notwithstanding, banana plays an insignificant role in Uganda's agricultural exports (Todd et al., 2008; MAAIF, 2009). Price fluctuations of *matooke* on the local market coupled with post harvest losses depending on the season of harvest are rampant (Guloba et al., 2007). The Government of Uganda therefore decided to invest in modelling the industrial processing of *matooke* into banana flour through the Presidential Initiative on Banana Industrial Development (PIBID) project as a remedy to the high post harvest losses. PIBID has set up a banana processing industry and once it is in full-scale operation, a lot of banana waste will be generated, considering 33% of waste generated for each bunch of *matooke* peeled (Bardiya et al., 1996). This would pose a waste disposal challenge, unless ways of utilising this waste are sought.

Anaerobic digestion of these wastes to generate biogas was identified as a promising way of utilising the waste, but information was inadequate about the optimal peel pre-treatment practices for biogas generation using banana peels and/or waste. Banemann (2009) suggested that an economically viable anaerobic digester requires a detailed feasibility study on the basis of the available

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substrates and the local conditions before construction to avoid degradation of the substrates during storage for a continuous stable process. Pakarinen et al. (2008) noted a 37 to 52% loss in methane yield from energy crops stored under suboptimal conditions and suggested that it is important to minimize energy losses during storage for feed material that may involve storage before use. Therefore, the objective of this study was to assess the changes in those physicochemical properties of *matooke* peels that affect biogas production of different cultivars under ambient storage conditions, and optimize methane yield under different peel particle size regimes in biochemical methane potential trials (BMP) (Zitomer et al., 2002; Alastair et al., 2008).

MATERIALS AND METHODS

Banana peel characterization

Four bunches from different *matooke* cultivars were bought from the local market in Kampala based on their availability. These included *Mbwazirume* (A), *Musakala* (B), *Nakitembe* (C) and *Nakinyika* (D). Peels from each cultivar (A, B, C and D) were put in correspondingly labelled boxes after peeling and equal volumes of peels were sampled from each box and mixed uniformly in another box resulting in the fifth sample of mixed peels from the four cultivars (E). Sample E was due to consideration that practically the *matooke* processing industry would discharge peels as a mixture of different cultivars processed. The changes in constituents of the peels stored under ambient conditions with respect to biogas production potential were assessed at one day, four and seven days of storage. Storage/ holding days were used as the blocking factor.

Sample peels in three replicates were analysed for: total solids (TS), volatile solids content (VS), moisture content (MC), total organic carbon (TOC), total nitrogen content (TON) and crude fibre (CF). Also, about 1 kg of sample was taken from each box, dried and stored for the BMP trial. MC, TS and VS were determined as described in APHA Standard Methods (1995). TOC was determined using method of Schumacher (2002). TON was determined by Kjeldahl method, while CF was determined according to AOAC (2005) method.

Biochemical methane potential trial

Dried banana peels of the five samples were taken to the biogas laboratory of Hohenheim University (Germany). Sample A was selected for particle size optimization due to its high prevalence in the area of the banana processing industry under construction. Three peel particle sizes of 1, 5 and 10 mm were used based on previous studies by Sharma et al. (1988), Moorhead and Nordstedt (1993), Helffrich and Oechsner (2003), Mshandete et al. (2006) and Alastair et al. (2008). Samples B, C, D and E were reduced to 1 mm of peel particle size each, Hay and concentrated animal feed were used as standard substrates according to Hohenheim University biogas laboratory standards and an inoculum from the running 400 L digester was used as a control and for microbial initiation (Rittmann and McCarty, 2001). Each of the test substrate of about 400 mg with 30 g of inoculum was prepared in three replicates in 100 ml batch digesters (retort samplers/syringes) set in a slow motor-driven rotor for continuous substrate mixing for 35 days hydraulic retention time (HRT) at mesophilic temperature of 37°C in an incubator.

Measurement of methane production

For each set of replicates whose biogas volume was found sufficient to be detected in the gas transducer at the time of monitoring, biogas volume and methane content were measured and recorded. Incubator temperature, air pressure, date and time at which measurements were taken were also recorded for biogas production based on norm conditions (Nm^3/kg VS): 273K and 101325 Pa according to Ludington (2006). Biogas from the substrate was corrected for biogas from inoculum. Methane content was measured using an AGM 10 model gas transducer (Sensors Europe GmbH, Germany) with a non-dispersive infra red (NDIR) sensor able to detect methane content in biogas within a range of 0 to 100%. The gas transducer was calibrated with standard gas having a methane content of 60.7% (v).

Optimization

The optimal peel particle size for biogas production was projected from a numerical optimisation of mean specific methane yield and mean methane content against particle size.

Data analysis

Statistical data analysis was carried out using GenStat (discovery edition 3) and design expert (Version 6.0, Stat-Ease, Inc., MN, USA; 2003) packages. GenStat (one-way ANOVA with blocking) statistical package was used in analysing physicochemical properties for their significance between the different peel cultivars and between storage intervals. Design expert (Response surface method-one factor) was used in numerical optimization of biogas.

RESULTS AND DISCUSSION

Banana peel characterization

After four days of peel storage, the peels' constituents changed sharply. The C/N ratios of all the peel variants fell within the optimum range of 25 to 32:1 (Bouallagui et al., 2003) for anaerobic digestion at day 4, but increased thereafter probably due to nitrogen being used up by microorganisms (Table 1). CF content was not sharply changed by day four but later increased sharply, which is detrimental to biogas production as the substrate with high fibre content requires longer hydraulic retention time to digest. VS decreased gradually during the four and seven storage days in comparison to day one, which implied that a lot of peel would be required per unit volume of digester as suggested by Mattocks (2002). MC by day four had a slight change, but had decreased by day seven, which also impacted negatively on biogas production. These results imply that in order to utilize matooke peels' potential as feedstock material for optimum biogas production, they need to be kept for utmost of four days to bring the nutrient limiting factor; the C/N ratio, (Alastair et al., 2008; Bouallagui et al., 2003) to its optimum range without affecting the other peel constituents that are also limiting in biogas production.

Analysis of variance of physicochemical properties data

Table 1. Variation of peel MC, VS, TS, C:N and CF with storage time for the five peel types.

Peel storage (days)	Peel type	MC (%) (wb)	VS (%)	TS (%)	C/N ratio	CF (%)
	Mbwazirume	84.17	91.90	15.83	34.80	1.37
	Musakala	86.13	90.31	13.87	27.08	0.99
1	Nakitembe	83.72	92.41	16.28	31.95	1.26
	Nakinyika	84.80	91.84	15.20	23.35	1.23
	Mixed	83.16	92.32	16.84	34.06	1.12
	Mbwazirume	84.37	87.83	15.63	29.93	1.18
	Musakala	85.67	89.10	14.33	25.72	1.07
4	Nakitembe	83.07	90.65	16.93	22.43	1.20
	Nakinyika	85.50	87.33	14.50	21.95	1.33
	Mixed	85.15	89.46	14.85	31.10	1.23
	Mbwazirume	77.59	89.66	22.41	33.04	1.95
	Musakala	82.03	83.66	17.97	25.95	2.29
7	Nakitembe	82.03	87.46	17.97	29.81	2.40
	Nakinyika	82.49	82.94	17.51	28.29	2.18
	Mixed	81.15	86.48	18.85	29.91	2.15

Table 2. Analysis of variance for C/N ratio.

Source of variation	d.f.	S.S.	M.S.	V.R.	F PR.
Storage days	2	41.038	20.519	2.54	
Cultivars	4	164.745	41.186	5.09	0.025
Residual	8	64.742	8.093		
Total	14	270.525			

Table 3. Analysis of variance for VS (%).

Source of variation	d.f.	S.S.	M.S.	V.R.	F PR.
Storage days	2	81.684	40.842	15.58	
Cultivars	4	19.501	4.875	1.86	0.211
Residual	8	20.975	2.622		
Total	14	122.159			

Table 4. Analysis of variance for TS (%).

Source of variation	d.f.	S.S.	M.S.	V.R.	F PR.
Storage days	2	41.524	20.762	13.03	
Cultivars	4	12.967	3.242	2.03	0.182
Residual	8	12.75	1.594		
Total	14	67.241			

showed that TS, VS, CF and MC were not significant at 0.05 α-level among the different banana peel cultivars used in this study. Blocking factor based on the number of days of peel storage under ambient conditions was effective since it was significant at 0.05 α-level for all tested peel properties (Tables 2 to 6). This implies that from day one onwards, when *matooke* was peeled, the peel constituents change significantly under ambient conditions. On the other hand, the C/N ratio was significantly different among the different cultivars (Table

Table 5. Analysis of variance for MC (%).

Source of variation	d.f.	S.S.	M.S.	V.R.	F PR.
Storage days	2	41.524	20.762	13.03	
Cultivars	4	12.967	3.242	2.03	0.182
Residual	8	12.75	1.594		
Total	14	67.241			

Table 6. Analysis of variance for CF (%).

Source of variation	d.f.	S.S.	M.S.	V.R.	F PR.
Storage days	2	3.30688	1.65344	75.28	
Cultivars	4	0.0564	0.0141	0.64	0.648
Residual	8	0.17572	0.02197		
Total	14	3.539			

Table 7. Mean values of biogas generated at 35 days HRT.

Substrate	Av. methane content (%)	Av. sp. biogas yield (Nm^3/kg VS)	Av. sp. Methane yield (Nm^3/kg VS)	CV (%) sp. methane yield (Nm^3/kg VS)	Av. TS (% FM)
Inoculum	63	0.078	0.049	1.7	2
Hay standard	53	0.565	0.297	2.2	93
Feed standard	52	0.677	0.351	0.8	90
A, 1 mm	51	0.552	0.281	1.6	91
B, 1 mm	52	0.510	0.267	5.0	93
C, 1 mm	52	0.511	0.266	5.2	94
D, 1 mm	52	0.543	0.281	1.0	93
E, 1 mm	52	0.534	0.276	3.3	93
A, 5 mm	53	0.550	0.294	6.4	91
A, 10 mm	55	0.484	0.266	4.8	91

Av. = Average; sp. = specific; Nm^3 = norm cubic metres (273K, 101325 Pa); VS = volatile solids; CV = coefficient of variation; TS = total solids; FM = fresh material; n = 3

2). This indicates that C/N ratio is cultivar specific. Considering the C/N ratio of cultivar E (Table 1), which represents mixed peels, it clearly supports Amon et al. (2007a, b) and Alastair et al. (2008) suggestions that a substrate of high C:N ratio can be co-digested with another of low or vice versa to bring the C:N ratio to the optimum range.

Biogas production from banana peels

Table 7 shows the mean values of quality and quantity of biogas that were measured. The low CV% between the replicates of the different individual substrates indicate that the experiment was precise.

Influence of cultivar on specific methane yield

Results reveal that banana peels from different cultivars had generally the same specific methane yield under anaerobic digestion as shown in Figure 1. Over 85% specific methane yield was obtained in the first ten days of the experiment, which indicate that banana peels' contribution to biogas production was during the first 10 days or less, which is a short HRT. Large scale biogas production using substrate materials with short HRT requires such material to be in plenty. Thus, a lot of

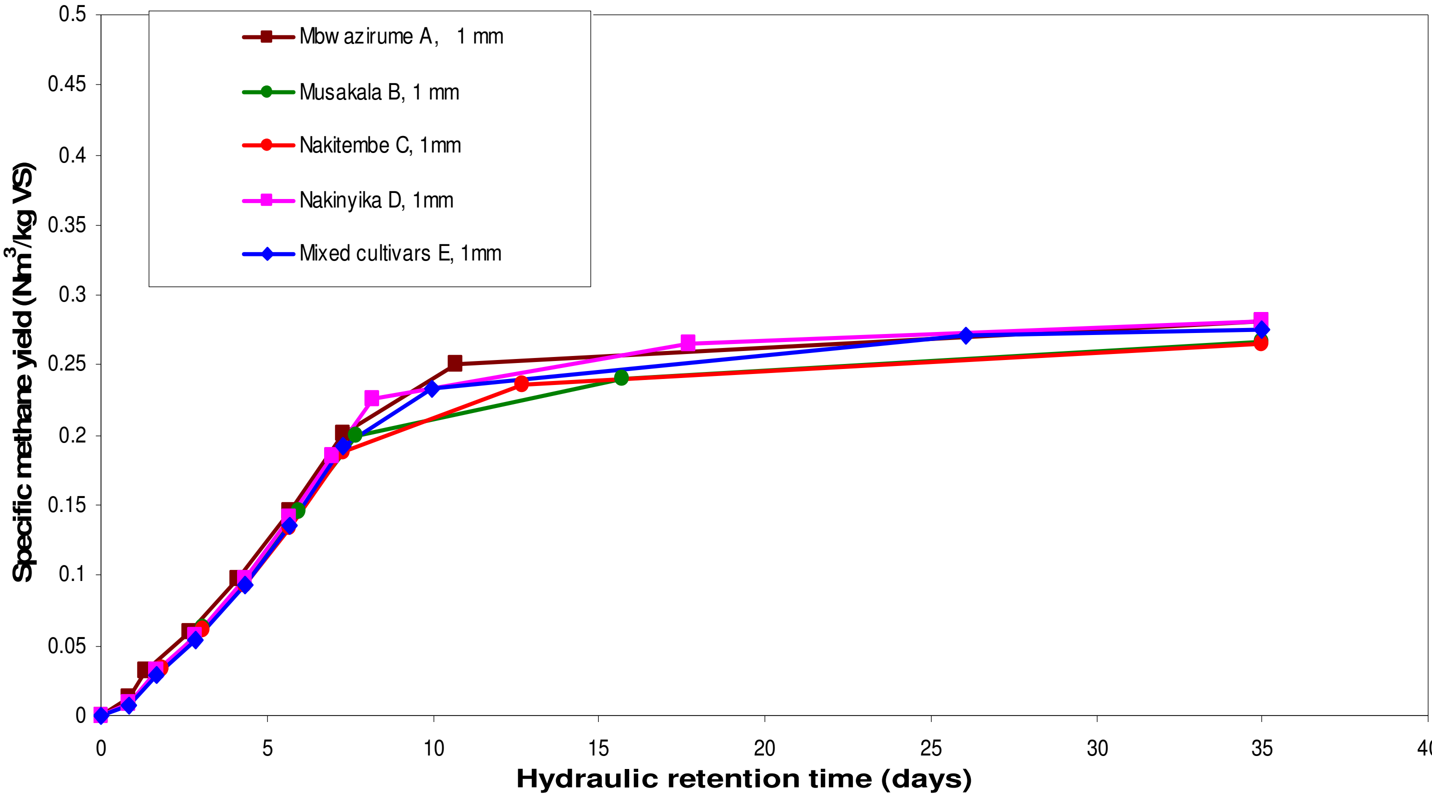

Figure 1. Mean cumulative specific norm-methane yield from different cooking banana cultivars

banana peels would be required to run the biogas plant on a large scale; to run a 4000 m^3 digester considering HRT of ten days requires 50 tonnes of fresh peels.

Additionally, short HRT may lead to washout of microorganisms, which would require recycling of the liquid slurry as suggested by Chynoweth and Isaacson (1987). Alastair et al. (2008) also reported that co-digestion with a high HRT feedstock is one way of reducing the amount of substrate material required.

Effect of particle size on specific methane yield

Results from Figure 2 show that cumulative specific methane yield is affected by particle size of the peels through the rate of production and not quantity of production. Considering the first ten days, 1 mm particle size showed a better performance compared to the 5 mm particle size. However, Alastair et al. (2008) suggests comparison between different substrates for performance to be their specific methane yields and the 5 mm particle size had higher yield than 1 mm particle size at 35 days HRT. Furthermore, Figure 3a shows that methane yield with respect to particle size follows the law of diminishing returns. Methane content on the other hand increased with increase in particle size (Figure 3b).

Considering the quality of biogas, the trend showed that particle size is a significant factor to methane content in biogas as shown by the response surface quadratic model of methane content which was significant at 5% alpha level (Table 8):

$$\text{Methane content} = +53.56 + 2.00A - 0.56A^2$$

Where, A is the particle size.However, looking at quantity of specific methane yield with respect to particle size, the regression model was not significant and thus, both the model and ANOVA table are not included here. Therefore, for optimum methane content and specific methane yield, an optimal particle size was projected from a numerical optimisation of mean specific methane yield and mean methane content against particle size Figure 3c). Figure 3c therefore projects the optimal particle size to be 6.73 mm at a desirability of 0.684. This agrees with Bardiya et al. (1996) who found out that chopped banana peels gave the highest rate of biogas compared to powdered peels.

Analysis of the effect of particle sizes on methane content shown in Figure 4 revealed that almost all measurements for 10 mm peel particle size were above 50% methane content, while for the 1 mm peel particle size, three measurements were far below 50% methane content in the duration of the experiment. This may explain the lower average methane content obtained for

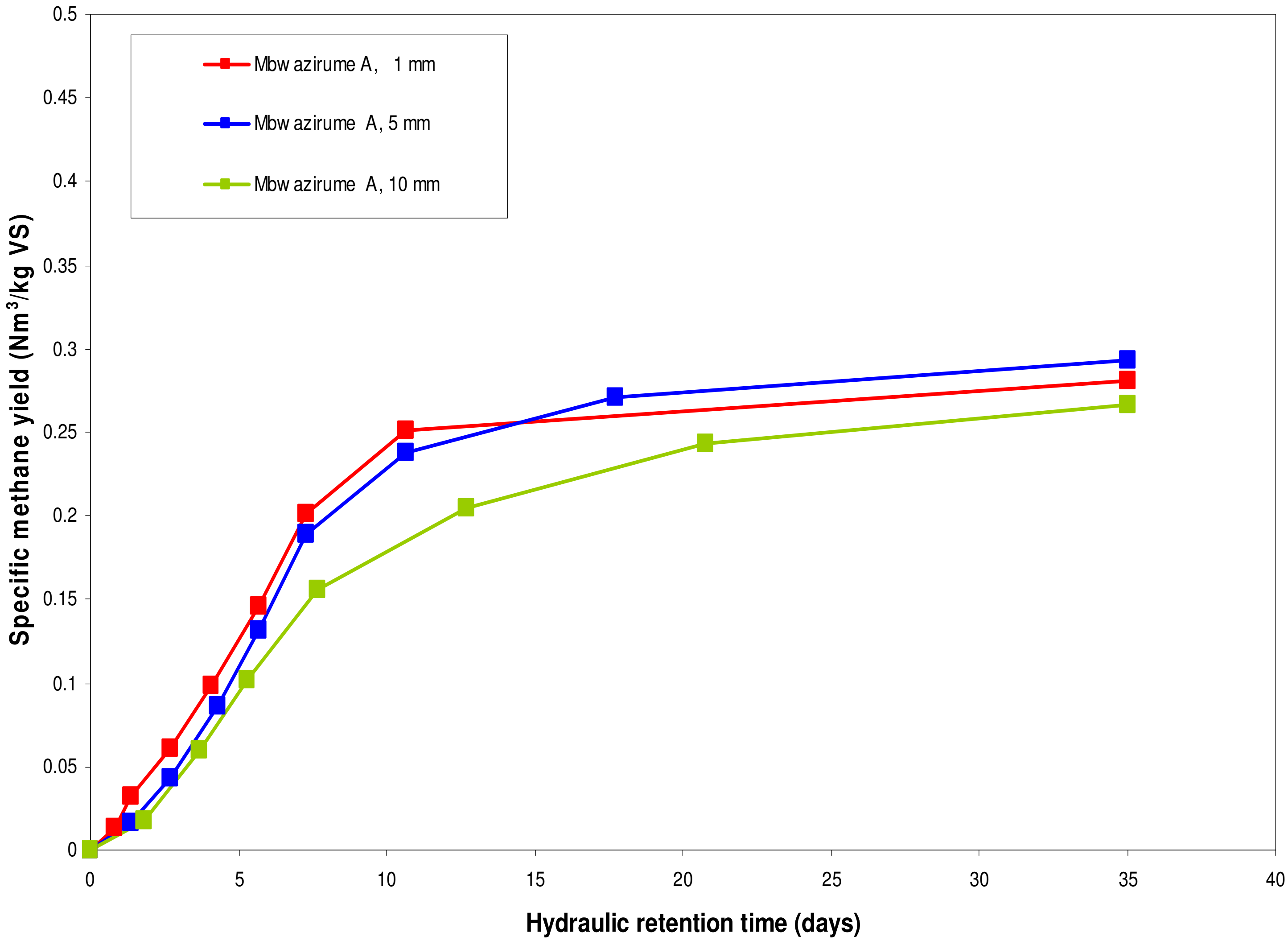

Figure 2. Mean cumulative specific norm-methane yield from varying particle size.

the 1 mm peel particle size in comparison to the 5 and 10 mm peel particle sizes. Thus, although the 1 mm peel particle size had a high rate of biogas production, its quality was low due to the low content of methane. Probably this is because when small particles are used, a large surface area is exposed to the hydrolysing enzymes, resulting into too many intermediate acids that cannot all be utilized by the slow methanogens for methane production, hence resulting into an acidic situation that affects the quality of biogas as reported by Palmowski and Müller (2000).

Conclusion

Fresh *matooke* peels have a higher C/N ratio than the optimum range for anaerobic digestion and are thus not a suitable feedstock unless the C/N ratio is adjusted. Pre-treatment of the *matooke* peels by storage under ambient condition for utmost of four days, however, adjusted the C/N ratio to the optimum range that favours anaerobic digestion without affecting other peel constituents that are also important in anaerobic digestion process. *Matooke* peels from different banana cultivars yielded methane in the same range as long as the particle size was the same. Particle size has a significant effect on the quality, but not quantity of methane yield. The projected optimal particle size of *matooke* peels for anaerobic digestion was 6.73 mm; however, further work is required to validate this projected optimal particle size.

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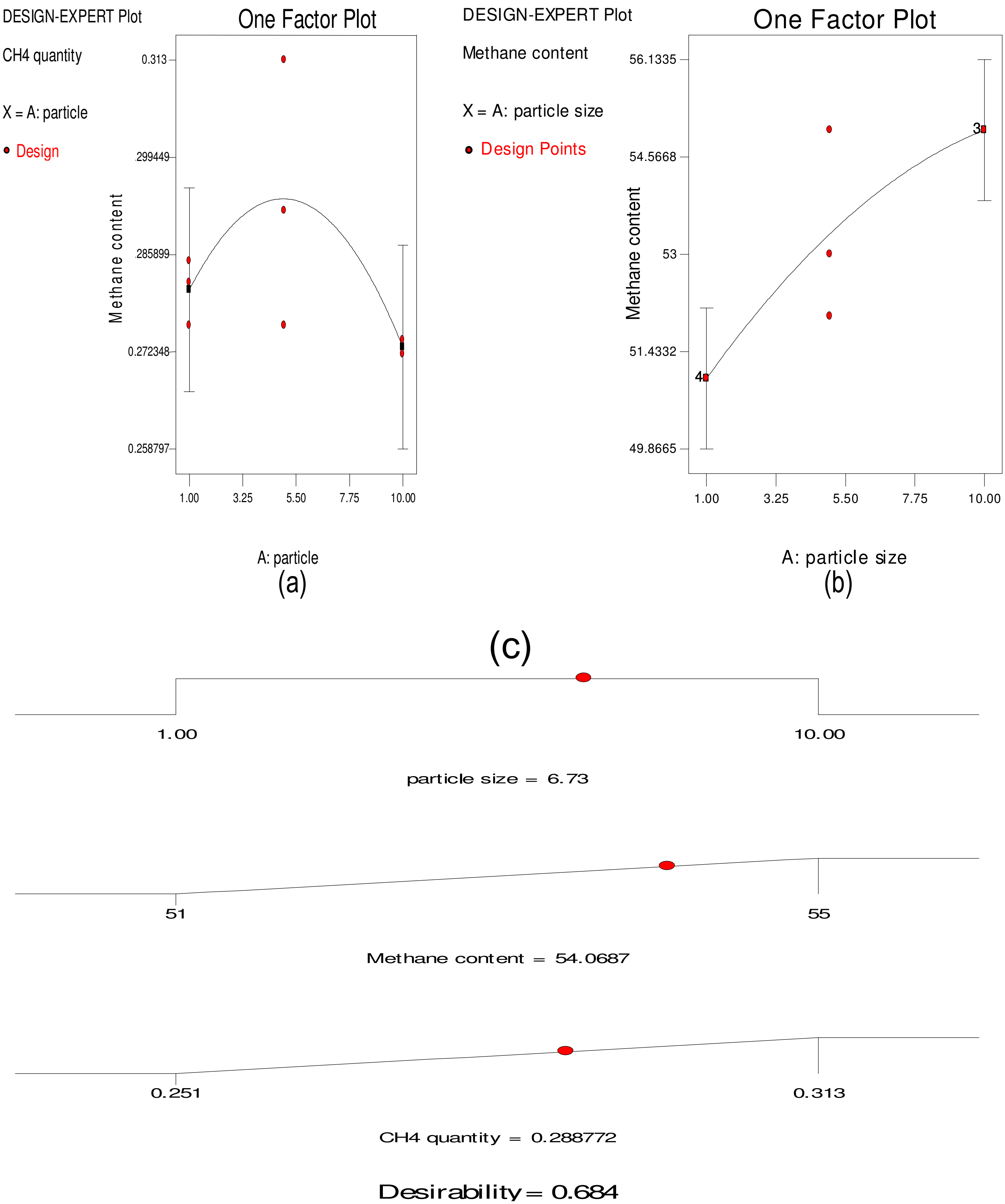

Figure 3. Effect of particle size on quantity and quality of methane.

Table 8. ANOVA for response surface quadratic model; response: methane content (quality of biogas).

Source		Sum of squares	DF	Mean squares	F-value	Prob > F
Model		20.21	2	10.1	10.83	0.0152
Significance	*A*	19.2	1	19.2	20.57	0.0062
	A2	0.58	1	0.58	0.62	0.4673
Pure Error		4.67	5	0.93		
Cor Total		24.88	7			

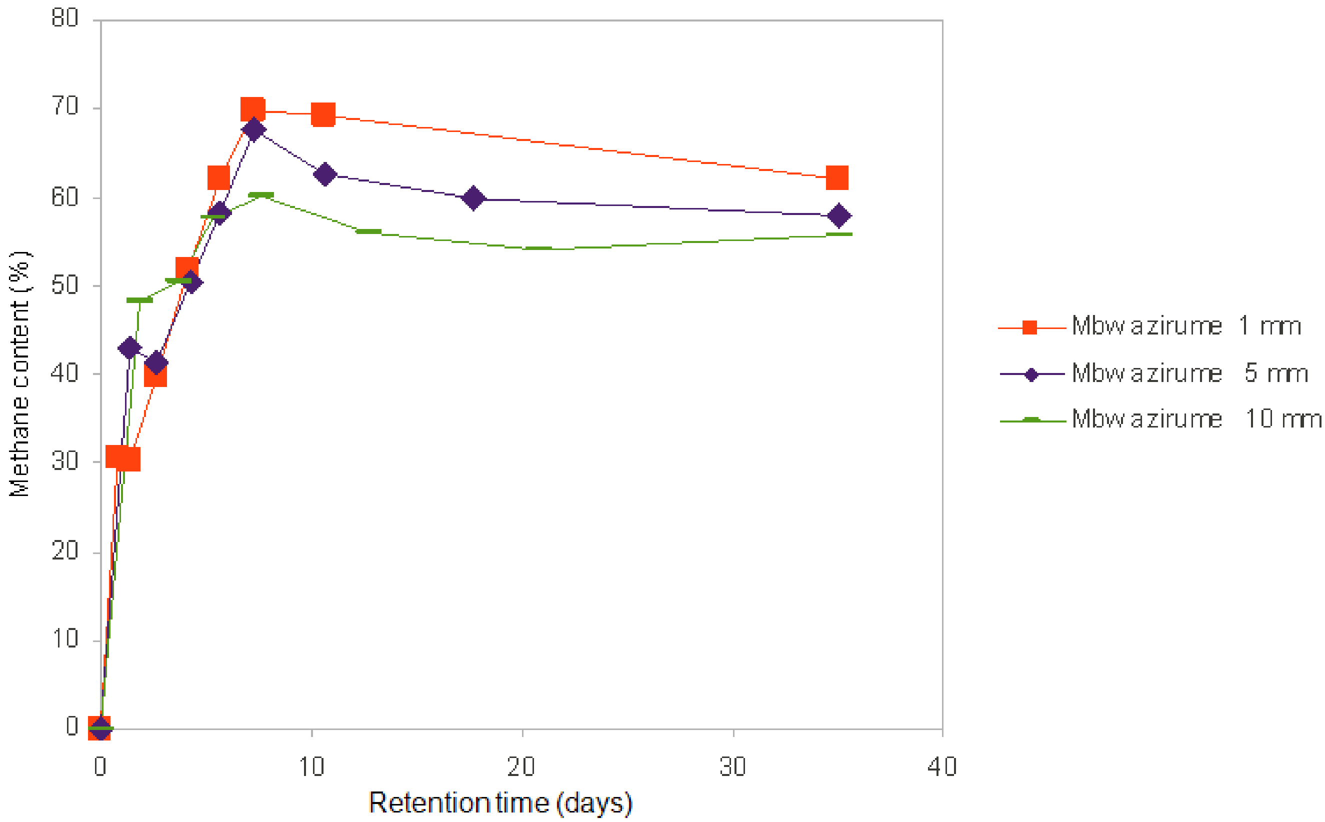

Figure 4. Effect of particle size on methane content and retention time.

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