

ENSILING OF POTATO PEELS WASTE FOR BIOMETHANE PRODUCTION: AN EVALUATION OF KINETIC PARAMETERS

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ABSTRACT

Pretreatment of lignocellulosic biomass is a necessary prerequisite for biofuel production. However, many of the pretreatment methods can lead to the formation of products that may adversely affect downstream processing. In this study, ensiling was used as a simple and cheap method of pretreatment to improve the biomethane potential of potato peel waste. Potato peel waste was ensiled for 100 days at ambient temperature in airtight bags. Using leachate collected from kitchen waste as inoculum, the biomethane potential of potato peel waste increased by 20.30 % after ensiling. Two kinetic models were used to fit the experimental biomethane potential of the substrates and kinetic parameters were estimated. The study showed that ensiling resulted in increased biodegradability of potato peel waste. The biomethane potential of the un-ensiled potato peel waste was 216.99 mL/gVS while that of the silage was 261.06 mL/gVS, making ensiling a suitable method for the pretreatment and preservation of potato peel waste for biogas production. The study also showed that the one-step-two-fraction kinetic model fitted the experimental biomethane potential better than the modified Gompertz model and therefore more appropriate to use in describing the anaerobic digestion of potato peel waste.

Keywords: anaerobic digestion, kinetic models, pretreatment

1 INTRODUCTION

The use of fossil fuels for energy generation is becoming less attractive due to its negative effect on the environment, fluctuations in prices and dwindling reserves [1]. Consequently, research on sustainable and eco-friendly alternatives to fossil fuel has been receiving intense attention over the past decades. One of such eco-friendly alternatives to fossil fuel is biogas, produced through a well-established process called anaerobic digestion (AD). During AD, a consortium of microbial communities decomposes a complex substrate in a sequential manner to form biogas [2]. The substrate for biogas production varies from one country to another depending on availability, potential and cost. For instance, maize and sugarcane are the major substrate for biogas production in Germany and Brazil respectively [3, 4]. However, the use of food crops for biogas production has adverse consequences on food and the food market [5], necessitating the use of non-food substrates like potato peel waste (PPW) for biogas production. Since the cost of substrate accounts for at least of 30 % of the total cost of biofuel production [6], the use of waste as feedstock will go a long way to significantly reduce the production cost of biofuel. Nigeria is one of the major producers of potato in Africa, producing about 4.0 million metric tons of the vegetable in 2020 [7]. One of the wastes

usually generated during the processing of potato is PPW, which, if not properly handled, has the potential to cause environmental pollution. The peel has been reported to be rich in carbohydrate and starch [8], making it a potential substrate for biogas production. However, PPW is a lignocellulosic biomass. Lignocellulosic biomass consists mainly of three major structural polymers which are cellulose, hemicellulose and lignin. Despite the huge availability of lignocellulosic biomass, these structural polymers enhance their recalcitrant nature, thereby making them resistant to biological degradation. In order to enhance the biological degradation of lignocellulose biomass during AD, their properties need to be altered through a process called pretreatment [9]. Different types of pretreatments can be used to enhance the digestibility of a lignocellulosic biomass. Such pretreatment could be physical, chemical, biological or a combination of all [10], depending on the nature of substrate and overall efficiency. Irrespective of the method used for pretreating a lignocellulosic biomass, a higher biogas production is almost always obtained. However, whether or not the additional biogas yield can compensate for the cost of pretreatment is a matter that must be determined before a particular pretreatment option is selected. One cheap and effective pretreatment method is ensiling. Ensiling is an effective method for the pretreatment and preservation of wet biomass. During ensiling, the water-soluble carbohydrates (WSC) contents of a substrate are converted to fermentation products like lactic acid, acetic acid and ethanol under anaerobic conditions. These fermentation products have been reported to alter the structural polymers of lignocellulosic biomass [11], making them less recalcitrant to AD. The formation of lactic acid reduces the pH of the system, thereby inhibiting microbial activities as well as preserving the substrate. Acetic acid ensures that the silage is stable when exposed to air during feed-out to reactors. Another important organic acid that can be produced during ensiling is butyric acid, which is produced by clostridia through the fermentation of sugars or lactic acid. The formation of butyric acid results in increased pH, energy loss and loss of total solid (TS) in the system. The major alcohol present in silages is ethanol. A high concentration of ethanol is an indication of yeast fermentation and usually leads to volatile solids (VS) losses. Studies on ensiling have been conducted over different ensiling periods as long as 370 days [12] and even as short as 7 days [13]. All these studies showed that ensiling is a good method to pretreat and preserve wet biomass like PPW for biogas production. Additionally, in order to enhance the efficiency of AD of PPW, it is necessary to understand the overall process performance of the bioreactor for an efficient control of process parameters needed for an optimal biomethane yield. One of the ways of describing the overall performance of a bioreactor is by the use of kinetic models. Parameters obtained from kinetic models that describe a given biochemical process are sometimes specific to substrate types and process parameters [14]. To the best of our knowledge, there is no available literature on the kinetic study of biomethane potential from ensiled PPW. The objectives of the present study were to investigate the effect of ensiling on the biomethane potential of PPW and estimate the kinetic parameters of the process.

2 MATERIALS AND METHODS

2.1 Substrate and inoculum

Potato peel waste was obtained from a private kitchen in Obudu, South-southern Nigeria. The peels were then grinded into fine particle sizes. The inoculum used for the biomethane potential test was a leachate stream obtained from a controlled waste collection point. The leachate was generated from an open 100 L vessel containing only kitchen waste and exposed to the environment. Wastes were accumulated in the vessel between January and April. The properties of the substrate and leachate are shown in Table 1.

Table 1. Mean (\pm standard deviation) properties of potato peel waste and leachate

Substrate	Parameter	Value
PPW	Moisture content (%FM)	84.78 \pm 1.73
	Ash Content (%TS)	4.59 \pm 0.23
	pH	6.17 \pm 0.18
	WSC (g/L)	3.29 \pm 0.07
	Carbon (%TS)	41.27 \pm 0.53
	Hydrogen (%TS)	6.01 \pm 0.02
	Nitrogen (%TS)	3.98 \pm 0.05
	Oxygen (%TS)	44.15 \pm 1.81
Inoculum	pH	4.37 \pm 0.21
	BOD (g/L)	8250 \pm 11
	COD(g/L)	12307 \pm 23
	Appearance	Dark
	Smell	Sewagesmell

PPW, potato peel waste; FM, fresh matter; WSC, water soluble carbohydrate; TS, total solids, BOD, biochemical oxygen demand; COD, chemical oxygen demand.

2.2 Ensiling

About 300 g of the grinded PPW were packed into airtight bags as previously described [12] in triplicates and stored at ambient temperature for 100 days.

2.3 Physicochemical Measurements

The total solids (TS) and volatile solids (VS) contents of the PPW and silages were determined using standard methods [15] and then corrected for loss of volatile acids and alcohols using appropriate equations [16] in order to avoid overestimation of biomethane yield. Prior to the determination of the pH and the analyses of fermentation quality of the fresh substrate and silage, each sample was mixed with deionized water in a ratio of 1:10 (w/w) and shaken (Innova 44, New Brunswick Scientific) at 110 rpm and 5°C for 24 hrs. The mixtures were centrifuged (Heraeus Megafuge 16R, Thermo Fischer Scientific, Waltham, USA) at 10,000 \times g for 10 minutes and the supernatant was filtered with a 0.1 μ m filter (MilliporeSigma, Canada). The filtrate was used to measure the pH using a Sen Tix 41 pH electrode (WTW, Germany) and to determine the concentrations of ammonia nitrogen (NH₃-N), water-soluble carbohydrates (WSC), organic acids and alcohols. WSC were analysed using an Azura HPLC system (Knauer GmbH, Germany) equipped with degasser, binary pump system, auto sampler, column oven, and refractive index detector (RID) set at 40°C. The contents of volatile fatty acids (VFA) and alcohols were measured by analysis on a 7890A gas chromatograph with a flame ionization detector (FID) (Agilent Technologies, USA) as described by Apelt [17]. NH₃-N concentration and chemical oxygen demand were determined using tests kits, Nessler reagent and Hack DR 2000 spectrophotometer (HACK LANGE GmbH, Germany). Biochemical oxygen demand was measured using the dilution method outlined by Fulazzaky [18]. Carbon (C), hydrogen (H) and nitrogen (N) content of the substrates were determined by means of an elemental analyser (True Spec, LECO Instrumente GmbH, Mönchengladbrach, Germany). Oxygen (O) content was calculated based on the ash content and analysed elemental composition.

2.4 Biomethane Potential Determination

The BMPs of the un-ensiled and ensiled substrates were measured using the AMPTS II (Bioprocess control, Sweden) following the manufacturer's procedure. Inoculum to substrate ratio (ISR) was 2.7 (VS basis). Additionally, a triplicate positive control consisting of 2.85gTS of microcrystalline cellulose (MCC) as well as triplicate negative control consisting of 400 mL of only inoculum were used to monitor the quality of the inoculum. The headspace of each reactor was flushed with nitrogen for about 2 min to ensure anaerobic conditions. Daily methane production of each reactor was recorded using the software Bioprocess Control (Lund, Sweden). The batch tests were conducted at a mesophilic temperature of 38°C for 31 days. Experiment was terminated when

the daily BMP over three consecutive days was less than 1% of the accumulated BMP in accordance with VDI 4630 guideline.

2.5 Kinetics of Biomethane Potential and Statistical Analysis

Two kinetic models were used to fit the cumulative methane production data. These models were the one-step-two-fraction model (OSTF) given in Equation 1, and the modified Gompertz model given in Equation 2. Parameters from the models were determined using a Solver add-in program in Microsoft Excel software (version 2016, Microsoft Corporation). SigmaPlot software (version 7.0) was employed to design kinetic figures. The correlation coefficient (R^2) and the root mean square error (RMSE) given in Equation 3 were the statistical indicators used to determine the fitness of the models to the experimental data. All data were analysed with Microsoft Excel using the Two-Way Analysis of Variance (ANOVA). Tukey's post hoc test was adopted to compare differences at 0.05 significant level. Pearson correlation analysis was used to evaluate the interdependence of fermentation products.

$$G_{(t)} = G_{(0)}[1 - \alpha e^{-k_1 t} - (1 - \alpha)e^{-k_2 t}] \quad (1)$$

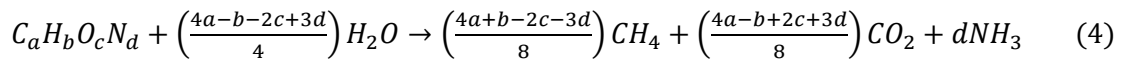
$$G_{(t)} = G_{(0)} \cdot \exp \left\{ - \exp \left[\frac{R_{max} \cdot e}{G_{(0)}} (\lambda - t) + 1 \right] \right\} \quad (2)$$

$$RMSE = \sqrt{\frac{ss}{n}} \quad (3)$$

where $G_{(t)}$ is the cumulative methane potential (mL/gVS) at time point t , G_0 is the maximum possible methane potential at a theoretically infinite digestion time (mL/gVS), R_{max} is the maximum methane production rate (mL/gVS/d), λ is the lag phase time (d), e is the Euler's number (2.7183), k_1 is the first-order degradation constant of fast degradable substrate (1/d), k_2 is the first-order degradation constant of slow degradable substrate (1/d), α is the fraction of readily degradable material, t is the duration of digestion (d), ss is the sum of difference of squares and n is the number of experimental runs.

2.6 Theoretical biomethane potential and biodegradability

The theoretical biomethane potential (TBMP) of the substrate before and after ensiling was determined at standard conditions using the Buswell's formula given in Equations 4 and 5.



$$TMP \left(\frac{mL}{gVS} \right) = 22415 \frac{\frac{4a + b - 2c - 3d}{8}}{12a + b + 16c + 14d} \quad (5)$$

The biodegradability (BD) of the substrates was calculated using Equation 6.

$$BD (\%) = \frac{\text{Experimental methane potential}}{\text{Theoretical methane potential}} \quad (6)$$

3 RESULTS AND DISCUSSION

3.1 Effect of Ensiling on Substrate Characteristics

The properties of PPW silage after 100 days are listed in Table 2. The WSC in the silage was significantly ($p < 0.05$) reduced after 100 days of ensiling. Reduction in WSC content in silages has also been reported by other authors [19, 20]. Ensiling also significantly ($p < 0.05$) reduced the pH of the silage from 6.17 to 3.79. Depending on the type of silage and TS content, the pH of a good silage should be between 3.7 and 5.0 [21]. Considering the TS values of the silage in the present study, the pH was an evidence of good ensiling. As also shown in Table 2, the predominant fermentation product in the silage was lactic acid as has also been reported for other good silages [12]. The low pH value obtained in the silage is as a result of lactic acid production in the systems [22]. Apart from lactic acid, there was also a significant amount of acetic acid in the silage, indicating that the substrate would be stable when exposed to air during feed-out to reactor. Lactic to acetic acid ratio was greater than 1, an indication that there was no abnormal fermentation in the silage [12]. The NH_3 -N content in the silage was below detectable limit, indicating that no protein degradation occurred [23], which is

another indication of adequate ensiling. Another indication that the silage was adequate was the absence of butyric acid, which would have resulted to energy loss in the system. There was no significant difference ($p < 0.05$) in the elemental composition of the silage compared to the fresh substrate as similarly observed in the ensiling of sugar beet leaves [14].

Table 2. Properties of potato peel waste silage after 100 days

Parameter	Unit	value
Moisturecontent	%FM	87.29 ± 1.39
Ash content	%TS	5.63± 0.21
WSC	g/L	0.28± 0.02
Aceticacid	g/L	4.51± 0.01
Lacticacid	g/L	6.83± 0.17
Butyricacid	g/L	ND
Ethanol	g/L	2.73±0.08
LA/AA	-	1.51± 0.03
Carbon	%TS	41.25± 1.37
Nitrogen	%TS	3.97± 0.13
Hydrogen	%TS	5.94± 0.06
Oxygen	%TS	44.19± 1.93
pH	-	3.79± 0.01
NH ₃ -N	g/L	ND

WSC, water soluble carbohydrate; LA, lactic acid; AA, acetic acid; NH₃N, ammonia-nitrogen; ND, not detected

3.2 Biomethane Potential Determination

The batch AD of the fresh substrate and silage were conducted at a mesophilic temperature of 37 °C (±1) for 31 days. The highest daily methane production occurred on the first day and then fell continuously in the silage. For the un-ensiled substrate, daily methane production increased until the third day (Figure 1), an indication that ensiling increased the digestibility of the substrate as also reported during the AD of Straw [24] Probably due to depletion of nutrients, methane production rate declined considerably after 20 days and the experiment was stopped after 31 days, in accordance with the VDI 4630 methodology. The BMPs of the silage (261.06 ± 14 mL/gVS) was significantly higher ($p < 0.05$) than the BMP of the un-ensiled substrate (216.99 ± 9 mL/gVS), an indication of the positive influence of ensiling. The BMP of the un-ensiled PPW in the present study compares with 217.8 mL/gVS reported by Achinas et al. [25].

3.3 Theoretical Biomethane Potential

The theoretical biomethane potential (TBMP) and biodegradability (BD) of the un-ensiled and ensiled PPW were estimated using equations 5 and 6 respectively. All substrates had a higher TBMP compared to the measured BMP, probably because both the biodegradable and non-degradable components of the substrates were assumed to be converted to methane during the calculation of TBMP. The BD of the silage was higher than that of the un-ensiled PPW (Figure 2), probably because the fermentation products degraded some structural carbohydrates during ensiling.

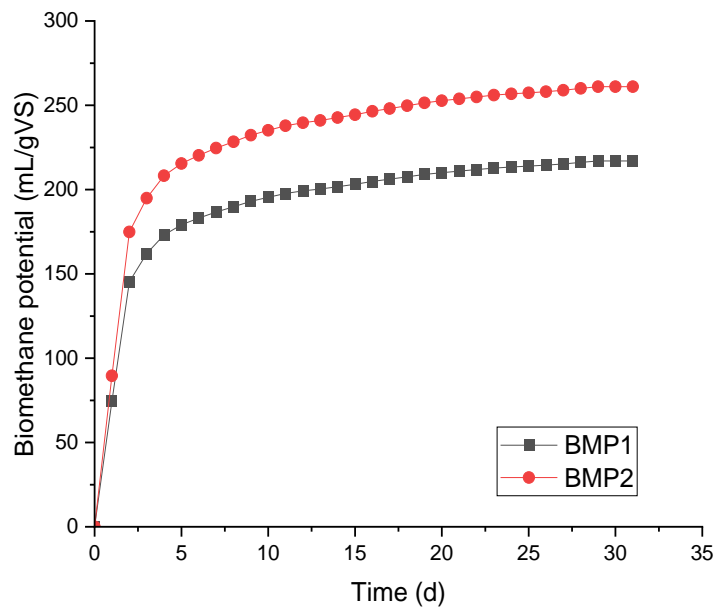


Figure 1. Cumulative biomethane potential of un-ensiled and ensiled potato peel waste (BMP1, biomethane potential of un-ensiled PPW; BMP2, biomethane potential of ensiled PPW).

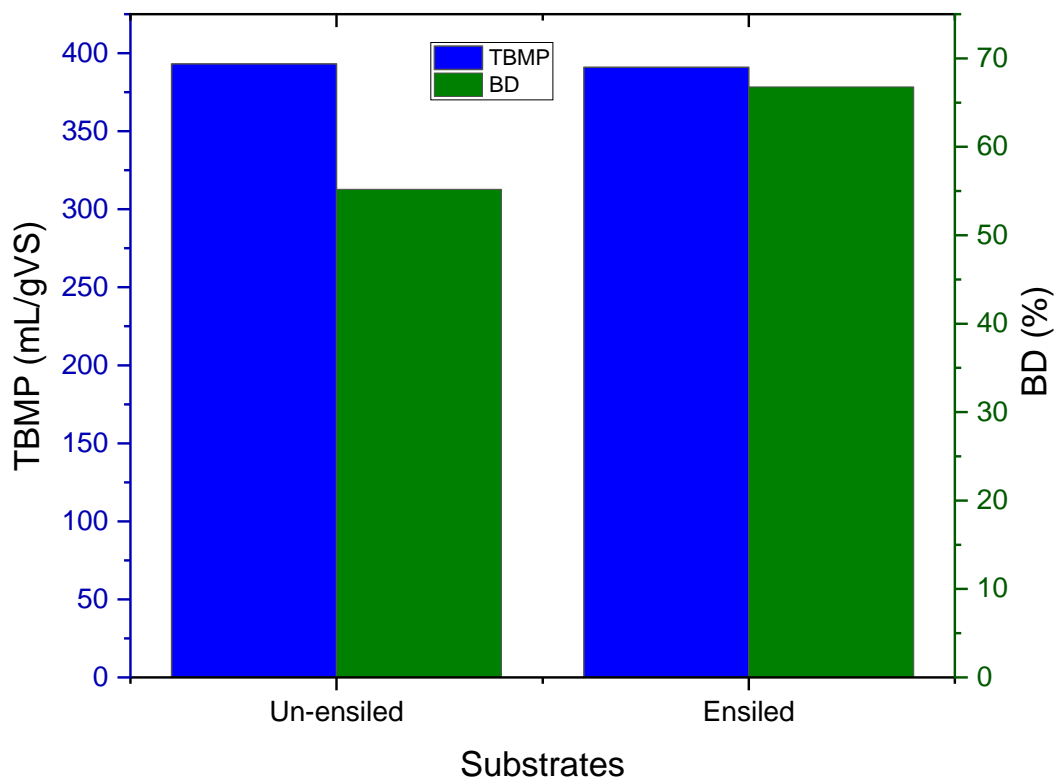


Figure 2. Theoretical biomethane potential and biodegradability of substrates

3.4 Kinetic Evaluation and Analysis

Obtaining a suitable model for the design and optimization of a continuous process for biomethane production from PPW is necessary. Therefore, two models were used to assess the accumulated BMP of the substrates. Experimental BMP were fitted to the models and kinetic parameters were estimated using Microsoft Excel software. The measured data and the predicted

curves from the models are shown in Figure 3. The two models gave a reasonably good fit to the measured data as seen from the high values of coefficient of determination, R^2 (Table 3). However, the one-step-two-fraction model (OSTF) fitted the measured BMP of the two substrates better than the modified Gompertz model (as seen from the lower value of RMSE) and therefore more appropriate in describing the BMP of PPW probably because, unlike the modified Gompertz model, the OSTF was derived on the assumption that complex substrates such as PPW used for AD contains both fast and slow degradable components. The deviation between the cumulative experimental and predicted BMP from the OSTF for the silage was 0.03% and 1.46% from the modified Gompertz model. From the OSTF, the values of hydrolytic constant of fast degradable components, k_1 were at least 8 times higher than the hydrolytic constants of slow degradable components, k_2 in the silage, an indication that components of ensiled PPW degrade at different rates. As shown in Table 3, ensiling increased the fraction of biodegradable matter, a confirmation that structural carbohydrate were degraded during ensiling. The maximum rate of methane production was also higher in the ensiled substrates compared to the un-ensiled material. However, ensiling had no effect on the kinetic constants of the substrates probably because the AD of both substrates occurred at the same temperature.

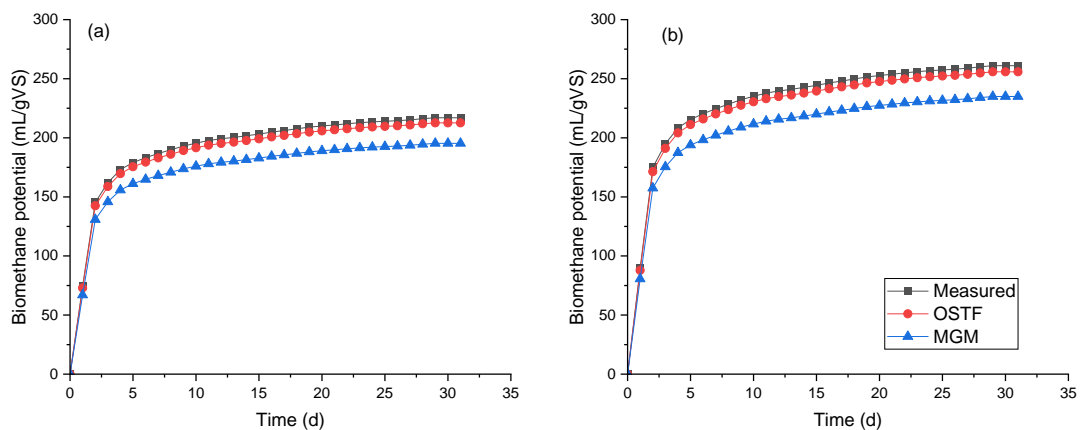


Figure 3. Kinetic fitting of biomethane potential of potato peel waste (a) before ensiling and (b) after ensiling (OSTF, one-step-two-fraction model; MGM, modified Gompertz model)

Table 3. Kinetic parameters* and statistical indicators from the models

Model		Unensiled PPW	Ensiled PPW
OSTF	G_0 (mL/gVS)	216.29	260.99
	α	0.52	0.73
	k_1 (/d)	0.37	0.38
	k_2 (/d)	0.04	0.04
	R^2	1.00	1.00
	RMSE	0.97	1.07
MGM	G_0 (mL/gVS)	215.96	257.25
	Rmax (mL/gVS/d)	74.44	89.56
	λ (d)	0	0.00
	R_2	0.98	0.99
	RMSE	1.51	1.49

*All parameters and their units are as defined in Equations 1 and 2

4 CONCLUSIONS

Potato peel waste has the potential as a substrate for biogas production. This potential can be improved if the substrate is pretreated by ensiling. Ensiling was seen to increase the fraction of biodegradable material in PPW as well as its biodegradability thereby leading to a higher biomethane

potential. In describing the kinetics of the anaerobic digestion of PPW, the one-step-two-fraction kinetic model was better than the modified Gompertz model.

REFERENCES

1. Egwu, U., Onyelowe, K., Tabraiz, S., Johnson, E. and Mutshow, A.D. (2022). Investigation of the effect of equal and unequal feeding time intervals on process stability and methane yield during anaerobic digestion grass silage. *Renewable and Sustainable Energy Reviews*, vol. 158, pp. 11-20. doi: 10.1016/j.rser.2022.112092.
2. Villa, R., Rodriguez, L.O., Fenech, C. and Anika, O.C. (2020). Ensiling for anaerobic digestion. A review of key considerations to maximise methane yields. *Renewable and Sustainable Energy Reviews*, vol. 134, pp. 1-10. doi: 10.1016/j.rser.2020.110401.
3. Theuerl, S., Herrmann, C., Heiermann, M., Grundmann, P., Landwehr, N., Kreidenweis, U. and Prochnow, A. (2019). The Future Agricultural Biogas Plant in Germany. *A Vision. Energies*, vol. 12, no. 3, pp. 1-32. doi: 10.3390/en12030396.
4. Hoffstadt, K., Pohen, G.D., Dicke, M.D., Paulsen, S., Krafft, S., Zang, J.W., Da Fonseca-Zang, W.A., Leite, A. and Kuperjans, I. (2020). Challenges and Prospects of Biogas from Energy Cane as Supplement to Bioethanol Production. *Agronomy*, vol. 10, no. 6, pp. 1-16. doi: 10.3390/agronomy10060821.
5. Brinkman, M., Levin-Koopman, J., Wicke, B., Shutes, L., Kuiper, M., Faaij, A. and Van der Hilst, F. (2020). The distribution of food security impacts of biofuels, a Ghana case study. *Biomass and Bioenergy*, vol. 141, pp. 10-19. doi: 10.1016/j.biombioe.2020.105695.
6. Stürmer, B. (2017). Feedstock change at biogas plants – Impact on production costs. *Biomass and Bioenergy*, vol. 98, pp. 228-235. doi: 10.1016/j.biombioe.2017.01.032.
7. FAOSTAT (2021). Food and Agricultural Organization of the United Nations, Retrieved from www.fao.org on 15.01.2022.
8. Arapoglou, D., Varzakas, T., Vlyssides, A. and Israilides, C. (2010). Ethanol production from potato peel waste (PPW). *Waste Management*, vol. 30, no. 10, pp. 1898-1902. doi: 10.1016/j.wasman.2010.04.017
9. Abraham, A., Mathew, A.K., Park, H., Choi, O., Sindhu, R., Parameswaran, B., Pandey, A., Park, H.J. and Sang, B. (2020). Pretreatment strategies for enhanced biogas production from lignocellulosic biomass. *Bioresource Technology*, vol. 301, pp. 12-25. doi: 10.1016/j.biortech.2019.122725.
10. Banu, J.R., Sugitha, S., Kavitha, S., Yakesh, K.R., Merrylin, J. and Kumar, G. (2021). Lignocellulosic Biomass Pretreatment for Enhanced Bioenergy Recovery: Effect of Lignocelluloses Recalcitrance and Enhancement Strategies. *Frontiers in Energy Research*, vol. 9, pp. 1-17. doi: 10.3389/fenrg.2021.646057.
11. Sun, H., Cui, X., Li, R., Guo, J. and Dong, R. (2021). Ensiling process for efficient biogas production from lignocellulosic substrates. Methods, mechanisms, and measures. *Bioresource Technology*, vol. 342, pp. 12-28. doi: 10.1016/j.biortech.2021.125928.
12. Undiandeye, J., Gallegos, D., Lenz, J., Nelles, M. and Stinner, W. (2022). Effect of Novel *Aspergillus* and *Neurospora* Species-Based Additive on Ensiling Parameters and Biomethane Potential of Sugar Beet Leaves. *Applied Sciences*, vol. 12, no. 5, pp. 1-10. doi: 10.3390/app12052684.
13. Ai, P., Zhang, X., Ran, Y., Meng, L., Elsayed, M., Fan, Q. and Abomohra, A.E.F. (2019). Biomass briquetting reduces the energy loss during long-term ensiling and enhances anaerobic digestion. A case study on rice straw. *Bioresource Technology*, vol. 292, pp. 12-19. doi: 10.1016/j.biortech.2019.121912.

14. Undiandeye, J., Gallegos, D., Sträuber, H., Nelles, M. and Stinner, W. (2022). Ensiling parameters in vertical columns and multiple kinetic models evaluation of biomethane potential of ensiled sugar beet leaves. *Biofuels (Latest articles)*, pp. 1-11. doi: 10.1080/17597269.2022.2059964.
15. Strach, K. (2016). Determination of total solids (dry matter) and volatile solids (organic dry matter). In: Liebetrau, J. (ed.) *Collection of Methods for Biogas. Methods to determine parameters for analysis purposes and parameters that describe processes in the biogas sector. Germany*, pp. 26-27.
16. Weissbach, F. and Strubelt, C. (2008). Correcting the dry matter content of grass silages as a substrate for biogas production. *Landtechnik*, vol. 63, no. 4, pp. 210-211.
17. Apelt, M. (2016). Determination of aliphatic, organic acids and benzaldehyde with headspace GC. In: Liebetrau J (ed) *Collection of Methods for Biogas: Methods to determine parameters for analysis purposes and parameters that describe processes in the biogas sector*, pp. 35-39.
18. Fulazzaky, M.A. (2013). Measurement of biochemical oxygen demand of the leachates. *Environmental Monitoring and Assessment*, vol. 185, no. 6, pp. 4721-4734. doi: 10.1007/s10661-012-2899-z.
19. Shah, A.A., Wu, J., Qian, C., Liu, Z., Mobashar, M., Tao, Z., Zhang, X. and Zhong, X. (2020). Ensiling of whole-plant hybrid pennisetum with natamycin and *Lactobacillus plantarum* impacts on fermentation characteristics and meta-genomic microbial community at low temperature. *Journal of the Science of Food and Agriculture*, vol. 100, no. 8, pp. 3378-3385. doi: 10.1002/jsfa.10371.
20. Agarussi, M.C.N., Silva, V.P., Paula, E.M., Vyas, D., Adesogan, A.T., Pereira, O.G. and Ferraretto, L.F. (2020). Effects of ensiling of whole-plant corn on silage processing score and fermentation and long-chain fatty acid profiles. *Applied Animal Science*, vol. 36, no. 2, pp. 167-171. doi: 10.15232/aas.2019-01941.
21. Kung, L., Shaver, R.D., Grant, R.J. and Schmidt, J.R. (2018). Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *Journal of Dairy Science*, vol. 101, no. 5, pp. 4020-4033. doi: 10.3168/jds.2017-13909.
22. Franco, R.T., Buffière, P. and Bayard, R. (2020). Cattle manure for biogas production. Does ensiling and wheat straw addition enhance preservation of biomass and methane potential. *Biofuels*, vol. 11, no. 6, pp. 671-682. doi: 10.1080/17597269.2017.1387751.
23. Herremans, S., Decruyenaere, V., Beckers, Y. and Froidmont, E. (2019). Silage additives to reduce protein degradation during ensiling and evaluation of in vitro ruminal nitrogen degradability. *Grass and Forage Science*, vol. 74, no. 1, pp. 86-96. doi: 10.1111/gfs.12396.
24. Xiao, Q., Chen, W., Tian, D., Shen, F., Hu, J., Long, I., Zeng, Y., Yang, G. and Deng, S. (2020). Integrating the Bottom Ash Residue from Biomass Power Generation into Anaerobic Digestion To Improve Biogas Production from Lignocellulosic Biomass. *Energy & Fuels*, vol. 34, no. 2, pp. 1101-1110. doi: 10.1021/acs.energyfuels.9b01898.
25. Achinas, S., Li, Y., Achinas, V. and Euverink, G.J.W. (2019). Biogas Potential from the Anaerobic Digestion of Potato Peels. Process Performance and Kinetics Evaluation. *Energies*, vol. 12, no. 12, pp. 1-13. doi: 10.3390/en12122311.