Volume 10, Issue 4, 2020, 5994 - 5999 ISSN 2069-5837
Biointerface Research in Applied Chemistry
www.BiointerfaceResearch.com
https://doi.org/10.33263/BRIAC104.994999
Original Research Article Open Access Journal
Received: 03.04.2020 / Revised: 24.04.2020 / Accepted: 26.04.2020 / Published on-line: 29.04.2020

Biogas production from kitchen waste acquired from COMSATS University Islamabad, Abbottabad campus (a pilot study)

Rashid Pervez [1], Iftikhar Raja [2], Qaisar Mahmood [2], Fayyaz Ali Shah [3], Yonghong Wang [1]

[1]Key Labrtary of Submarine Geosciences and Prospecting Techniques, MOE, College of Marine Geosciences, Ocean University of China, Qingdao 266100, PR China
[1]Laboratory of Marine Geology and Environment, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266237, China
[2]Department of Environmental Sciences, COMSATS University Islamabad, Abbottabad campus 22060, Pakistan
[3]Hazara University, Front of Multipurpose Hall, Dhodial, Mansehra, Khyber Pakhtunkhwa 21120, Pakistan
*Corresponding author e-mail address: ***rashid.pervez@hotmail.com*** | Scopus ID 57202378196

ABSTRACT
To reduce human dependence on the mitigation of fossil fuels and climate change require switching to a fully renewable energy system with low or nil associated emission of greenhouse gases. The present study was conducted in CIIT Abbottabad to determine the amount of kitchen waste (K.w) generation, and its subsequent potential for biogas production during anaerobic digestion. Two bio-reactors were operated to estimate the biogas production for cooked and un-cooked (K.w). The (K.w) was quantified into cooked and un-cooked (K.w) category, and for 30 days batch bioreactor was operated to assess the biogas production. The quantity of cooked and un-cooked (K.w) generation was 6~18, and 8~30 kg per day via Salman Firdous, and 8~22, and 12~27 kg per day by Azeem Shehzad cafeteria. Our finding depicted that biogas production was measured higher (40 times) in cooked than un-cooked (K.w). It was also noticed that biogas production was done in three phases i.e. lag, log and steady phase. The higher biogas production is due to the effect of thermal pretreatment during cooking that causes the softening of various organic substrates like hemicelluloses, celluloses, fats and proteins. It acted like a pretreatment and aided in the microbial action which resulted in very high biogas yields from cooked (K.w). Our outcomes were significant to generate renewable energy from (K.w) at institutes level to overcome the energy shortcoming in less developing countries like Pakistan.
Keywords: *Biogas, Cooked, Uncooked, Kitchen waste (K.W), Production, Anaerobic digestion.*

1. INTRODUCTION

To reduce the environmental impact of energy supplies, Biomass has a vital source of renewable energy [1, 2]. Biogas energy can generate from several sources. The consumption of biogas as a source of energy can improve the energy level, employment opportunities, and development in different regions [3]. For biogas production, various factors can be influenced during digestion such as temperature, pH, carbon/nitrogen ratio, mixing of material, water/solids ratio, retention time and size of the particle [4], because of high biodegradability for co-digestion, food waste is an appropriate material for digestion [5]. However, in the Batch digester, diary manure was reported as an efficient source of biogas production [6], vegetables and fruits could be beneficent if they are treated in an appropriate way [7]. In a continuously stirred tank reactor (CSTR), co-digestion of different vegetables, fruits and animal wastes under the mesophilic condition develop the efficacy of biogas production. Whereas, Bio-methane boost from 230 to 450 L per kg by the addition of vegetable wastes and increase 20 to 50 % bio-methane concentration [8].

Food i.e. peels waste contains starch and recognized as a rich source of energy [9]. The biogas production from several mixtures like, manure of bovine, chicken, and husk of olive has been studied on an experimental basis [10]. Co-digestion of barely wastes and (K.w) generate 15% contents of methane than co-digestion of (K.w) by itself [11]. To accelerate the biogas production at the local level, crops have a rich source of energy and have considered the best option for biogas energy, and around 1500 million tons of agricultural biomass could be converted into energy according to European Union (EU) [12]. Biogas production undergoes the different climatic conditions within the range of 0–97 °C temperature [13]. Biogas is a source of renewable energy and has been consuming in couple of countries around the globe [14]. Numerous wastes such as vegetables frozen fruits, juices, leads to produce a substantial quantity of waste which is organic as nature (10–65% as a raw substance), (2–8 tones sludge/100 tons of processed raw substance). Additionally, such organic waste is being used to feed the different animals or wasted as a landfill, though landfill use is not suitable and up to the mark by the new regulation. Therefore, such organic wastes are highly decomposable [15]. A different form of vegetations is operating for energy production worldwide by several methods [1, 16]. Municipal sludge, animal manure, and agricultural biomass are more prominent for co-digestion in recent years [17].

Fruits, vegetable waste and sludge are the most proper input material for anaerobic digester that helps for biogas production. It overcomes the usage of fossil fuels and has a positive role in economic prospective [18]. Fruits include moisture and organic contents; thus, anaerobic digestion is the best method for biogas production from fruit waste [19]. The present study aims to underline the efficiency of biogas plant using (K.w) at the laboratory level. The significance of our analysis is to highlight the (K.w) generation at the pilot scale which can be employed as a source of renewable energy to full fill the energy deficit after proper treatment in less developing countries like, Pakistan.

2. MATERIALS AND METHODS

2.1. Characterization and Quantification of kitchen waste.

The (K.w) was segregated into cooked and un-cooked category. The cooked and uncooked foods were collected from the cafeterias of COMSATS IIT, Abbottabad. Cooked food was comprised loaf of wheat, rice, meat remains, pulses, chicken remains, potato, vegetable, spinach, tomato, potato, radish, peas, tomato, and pumpkin. While, cauliflower, cabbage, spinach, cucumber, tomato, potato peels, onion, capsicum, radish, pumpkin, and carrot were the composition of un-cooked food. To overcome the size of different foods, it has been shredded into small fragments for Batch Reactor process, and later dried for 2 weeks.

2.2. Lab scale setup.

Batch anaerobic digestion tests were operated to determine the biodegradability of the uncooked and cooked food. For both substrates, reactors were run as triplicates. 25 g of uncooked and cooked waste were put into the reactors with water i.e. 100 ml and inoculums 50 ml. Total 175 ml of both wastes and 325 ml headspace in reactors. The experiment was conducted at (35 °C) under the mesophilic condition for 30 days in water bath. Inoculum was carried out by the biogas plant of RION (company name) that was functioned in Havelian Abbottabad, Pakistan. The VS of inoculum was 50%. and TS was 56 %. The inoculums and substrate ratio were 2:1. 0.1 Normal solution was prepared as a stock solution. Figure 1 shows the experimental setup [20] to assess the biogas production.

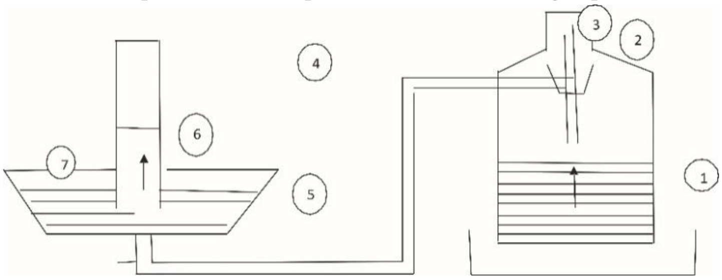

Figure 1. Experimental set up of Biogas unit at lab scale
(1) Water Bath (2) Reactor (3) Rubber Stopper (4) Gas Pipe (5) Water Tub (6) Inverted Graduated Cylinder (7) Acidified water.

2.3. Volatile solid (VS %) & Total Solid (TS %).

The VS and TS substrates of cooked and un-cooked waste are calculated using the following formulae

$$VS=\frac{\text{Weight of total}-\text{weight of volatile}}{\text{Weight of sample}-\text{weight of dish}}\times 100$$

$$TS=\frac{\text{Weight of total}-\text{weight of dish}}{\text{Weight of sample}-\text{weight of dish}}\times 100$$

The characteristics of both cooked and uncooked food are mentioned in Table. 1

Table 1. chemical characteristics of kitchen waste.

Food Category	TS (%)	VS (%)
Cooked Kitchen waste	25	31
Un-cooked Kitchen waste	3.7	2.3

2.4. Generation of (K.w) at COMSATS IIT, Abbottabad.

COMSATS, IIT, Abbottabad offers accommodation facilities to accommodate the students. To adjust the students in university dormitory, three hostel blocks approximately 1000 boys which are adjusted in two blocks and more than 200 girls' students are staying in one block according to hostel management of COMSATS, IIT, Abbottabad. There are two main cafeterias (Azeem Shahzad and Salman Firdous) mainly providing food services to students including faculty members. Other than that, the meeting of officials, seminars, conferences also used these cafeterias for food on many occasions. Besides, few small cafeterias such as the engineering cafeteria, tea shop, fast food and Dhaba are also facilitating and contribute to generate (K.w). The dumping site i.e. (open dump) for all types of solid waste is located near to parking area of the campus. All waste has been dumped openly in that area without any proper treatment and management on a regular basis. As a result, it leads to the release of toxic chemical and causes unpleasant environment within the campus and surrounding area.

The trend of generation of (K.w) in both cafeterias i.e. Azeem Shahzad and Salman Firdous cafeterias are shown in (Figure 2 and 3).

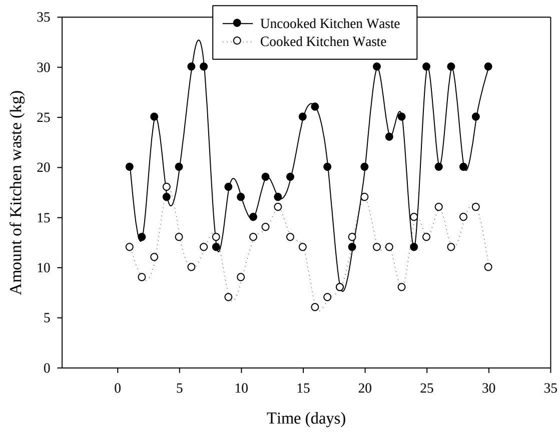

Figure 2. Trends in kitchen waste generation in Salman Firdous cafeteria for one month.

The range of cooked (K.w) in Salman Firdous cafeteria was 6~18 kg per day; although for un-cooked (K.w), it was estimated 6~18 kg per day.

Similarly, in Azeem Shehzad cafeteria the range of cooked (K.w) was 8~22 kg per day; and it was 12~27 kg per day for un-cooked (K.w).

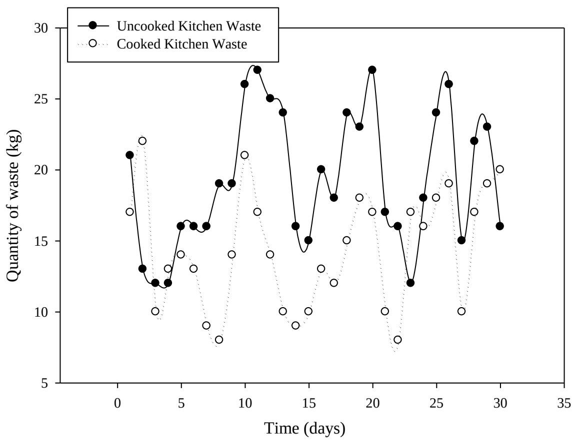

Figure 3. Trends in kitchen waste generation in Azeem Shehzad cafeteria for one month.

2.5. Biogas Production.

The biogas production via (K.w) was done in batch mode reactor, which is shown in Figure 1. Two reactors (R1 and R2) for cooked and un-cooked (K.w) has been installed at laboratory of COMSATS, IIT Abbottabad. The addition of substrate and inoculums in reactor was followed at 35 °C in water bath tank. Bioreactor was filled with inoculums and substrate with a ratio of 2:1. The amount of substrate was 25 g for each waste in both reactors. While one third space was reserved in the reactor for biogas accumulation.

3. RESULTS

Two bio-reactors were operated for cooked and uncooked (K.w). The data for biogas production in bio-reactor which were fed for un-cooked and cooked (K.w) is shown in (Figure 4 & 5). On the basis of these outcomes, it was concluded that the biogas production was completed in three phases during the operation such as lag, log and steady phase.

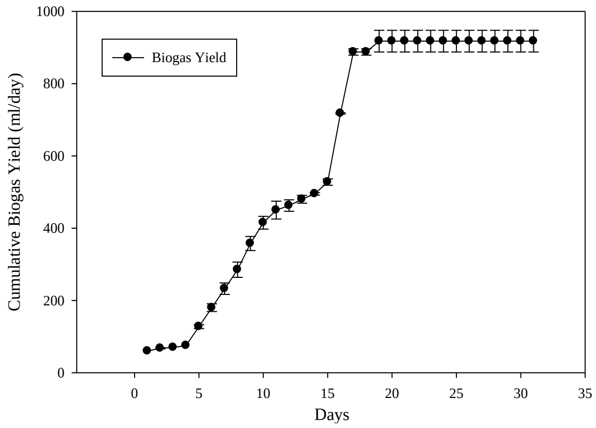

Figure 4. The biogas production in R1 during 30 days from un-cooked kitchen waste.

On the behalf of Figure 4 and 5, It has been depicted that 1st to 4th day during the process was lag phase followed by 5th to 20th day was log phase because a sharp increase has noticed in the value of biogas production (un-cooked K. w) and considered as a log phase.

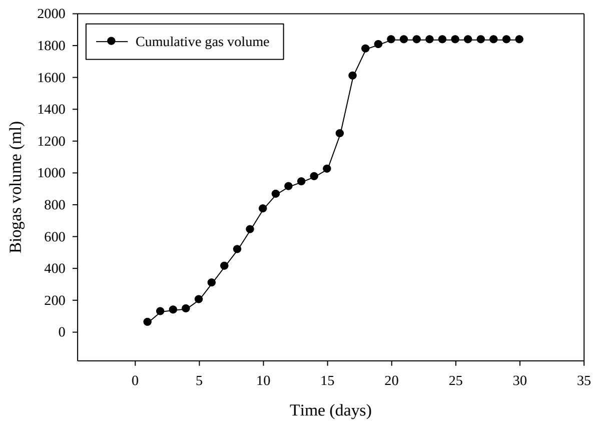

Figure 5. Cumulative biogas production in R2 from un-cooked kitchen waste.

A steady phase was assessed after the 20th day in which no sharp increase or decrease value observed for biogas production for un-cooked (K.w). Afterward, the process became uniform and was maximum after 20th days. Whereas, rapid biogas production was calculated during 15th to 20th days of lab analysis.

Similarly, higher biogas production was noted in cooked (K.w) which was around 40 times greater than un-cooked (K.w). The cumulative biogas production on daily basis for cooked kitchen food has been shown in Figure 6. However, there was a distinct variation in cumulative biogas production from un-cooked (K.w) on a regular basis as compared to cooked (K.w). The lag period was shortened beyond 4 days in cooked (K.w). Later, a steady phase was prominent from 6th to 30th for cooked (K.w). In last, at the end of month, the cumulative biogas volume was approximately 81.5 liters for cooked (K.w) and was up to 2 liters for un-cooked (K.w).

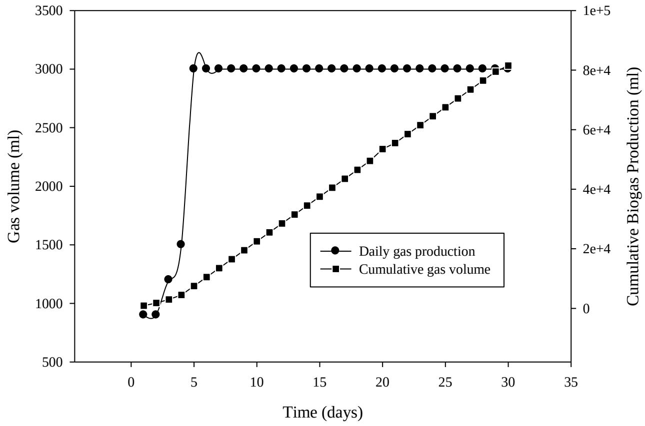

Figure 6. Daily and cumulative biogas production from cooked kitchen waste.

Anaerobic digestion technology is applied for the treatment of different food wastes to produce renewable energy with several byproducts such as carbon which can be consumed as a fertilizer and soil conditioner. Currently, numerous authorities recommend at local scale and suggest initial treatment of food waste and endorse anaerobic digestion method being the best choice for the treatment of organic wastes. Even though, if such wastes have to operate with other technologies, the outcomes from such analysis will become beneficent for operation and design to those processes. Anaerobic digestion can be utilized for the treatment of various types of organic wastes including sewage sludge, industrial wastewater, organic fraction of municipal solid and agricultural wastes. Thereafter, anaerobic digestion, residual sludge could be further treated with composting and mineralize residual portion of degradable organics to keep away from many pathogens that can reduce the efficacy of anaerobic digestion process. Afterward of composting, anaerobic sludge is beneficent and could be recycled as a fertilizer with a great amount [21, 36].

The difference in the operative factors such as feeding frequency, type of reactor etc., these discrepancies among different analysis might be exaggerated via changeability in food composition on the regional scale. To affect the biogas production, Fat content is one of the utmost important factors in kitchen waste because anaerobic digestion process undergoes challenging in fat rich waste and long chain fatty acid formation, and considered inhibitory to methanogens [22]. Microbes involve diverse element which acts as a nutrient for biogas production and their balance growth is necessary and vital for anaerobic digestion [23]. C/N in food waste is an essential parameter to affect the anaerobic digestion [24]. Mostly, C/N with range from 20–30 is appropriate for suitable anaerobic digestion. Most of the analysis accomplished 15–20 optimum value for C/N ratio, [25] documented that anaerobic digestion of green and food waste can work efficiently with C/N ratio from the range of 19:6. Whereas, [26] concluded, carbon-based substrates are well digested with C/N ratio 25 and lower initial C/N ratio is beyond 20.

The anaerobic digestion process in which soluble organic materials rapidly enhance biodegraded microbiologically. Therefore, the high molecular weight compounds and insoluble organic materials, proteins and polysaccharides are hydrolyzed in the solvable organic substrate. However, hydrolysis phase is considered as limiting rate phase [27], Anaerobic digestion is not a simple phenomenon that mainly relies on microbial activities and their assemblage for biogas production from organic substrate. Several reactions (e.g., acidogenesis, hydrolysis, methanogenesis and acetogenesis) carried out simultaneously in one digester. Moreover, the rates of acetogenesis and acidogenesis are greater as compared to methanogenesis with a huge organic load. Additionally, the higher production of methane was documented in numerous studies [28]. [29], found higher CH_4 yield at lab scale with the anaerobic digestion of vegetable and fruits waste.
The methane (CH_4) production decreases due to CO_2 formation with the passage of time. It happened as a result of higher NO_3–N concentration that causes inhibitory action due to persistence of few compounds which intermediate and produced by denitrification (e.g., N_2O, NO, nitrates and NO_2), enrich the nitrates level by enrichment of oxidation reduction potential (ORP) level, and also the effect of biochar to reduce the CH_4 production [30, 37]. Batch experiment was performed triplicate and biogas production was calculated through the liquid displacement method in previous studies [8].

The low production of biogas recognized from orange peels [31], and it is due to the existence of antimicrobial substances (limonene) that kill and inhibit microbes in digester. Low pH value in digester is likely to occur due to domination of acid phase [32]. In anaerobic digestion, the pH numbers of various species lie from the range of 5.5–8.5 [33], but the growth of methanogenic bacteria follows the pH values within the range of 7 to 8.5. The range of carbon (C) and nitrogen (N) varies from 20 and 30 for appropriate biogas production from Biomass [34]. The utilization of different substrates contained synergistic effects in most of the cases during biogas production [35, 36, 37] and pretreatment is essential for efficient outcomes [38]. The present study on cooked and un-cooked (K.w) concludes that cooked (K.w) is a better option for biogas production and an estimated 40 times greater than un-cooked (K.w) in pilot study.

The greater value of cooked (K.w) was because of thermal effect that triggers the softening of different carbon–based substrates such as hemicelluloses, celluloses, fats and proteins. Cooked (K.w) was already pretreated and boost to microbial activities for greater biogas production than un-cooked kitchen waste.

4. CONCLUSION

A difference was observed in the amount of (K.w) generation at COMSATS, IIT campus Abbottabad. The calculated value of cooked (K.w) was 6~18 kg per day; and, 8~30 kg per day for un-cooked KW from Salman Firdous cafeteria.

Similarly, the (K.w) generation via Azeem Shehzad cafeteria was 8~22 kg per day for cooked and 12~27 kg per day for un-cooked (K.w).

The biogas production was done in three phases throughout the examination i.e. lag, log and steady phase.

The cumulative biogas volume of cooked (K.w) was almost 40 times greater than un-cooked food.

The cumulative volume of biogas on 30th day was recorded 81.5 liters for cooked and 2 liters was un-cooked (K.w).

Biogas production from (K.w), specifically cooked (K.w) is the best option to overcome energy crises to some extent and preserve the environment.

5. REFERENCES

1. Najafi, B.; Ardabili, S.F. Application of ANFIS, ANN, and logistic methods in estimating biogas production from spent mushroom compost (SMC). *Resource, Conservation and Recycling* **2018**, *133*, 169–178, https://doi.org/10.1016/j.resconrec.2018.02.025.
2. Ardolino, F.; Parrillo, F.; Arena, U. Biowaste-to-biomethane or biowaste-to energy? An LCA study on anaerobic digestion of organic waste. *Journal of Cleaner Production* **2018**, *174*, 462–476, https://doi.org/10.1016/j.jclepro.2017.10.320.
3. Gwehenberger, G.; Narodoslawsky, M. Sustainable processes. The challenge of the 21st century for chemical engineering. *Process Safety and Environmental Protection* **2008**, *86*, 321–327, https://doi.org/10.1016/j.psep.2008.03.004.
4. Hennchen, B. Knowing the kitchen: Applying practice theory to issues of food waste in the food service sector. *Journal of Cleaner Production* **2019**, *225*, 675–683, https://doi.org/10.1016/j.jclepro.2019.03.293.
5. Aracil, C.; Haro, P.; Giuntoli, J.; Ollero, P. Proving the climate benefit in the production of biofuels from municipal solid waste refuse in Europe. *Journal of Cleaner Production* **2017**, *142*, 2887–2900, https://doi.org/10.1016/j.jclepro.2016.10.181.
6. Zhang, B.; Dixon, N.; El-Hamalawi, A. Development and Evaluation of a Phase Relationship for MSW. *Waste and Research Management* **2010**, 163, 67–75, https://doi.org/10.1680/warm.2010.163.2.67.
7. Liu, X.; Xu, Q.; Wang, D.; Zhao, J.; Wu, Y.; Liu, Y.; Ni, B.J.; Wang, Q.; Zeng, G.; Li, X.; Yamg, Q. Improved methane production from waste activated sludge by combining free ammonia with heat pretreatment: Performance, mechanisms and applications. *Bioresource Technology* **2018**, *268*, 230–236, https://doi.org/10.1016/j.biortech.2018.07.109.
8. Callaghan, F.J.; Wase, D.A.J.; Thayanithy, K.; Forster, C.F. Continuous Co-digestion of Cattle Slurry with Fruit and Vegetable Wastes and Chicken Manure. *Biomass and Bio energy* **2002**, *22*, 71–77, https://doi.org/10.1016/S0961-9534(01)00057-5.
9. Bamgboye, A.I.; Adelekan, B.A. Comparison of Biogas Productivity of Cassava Peels Mixed in Selected Ratios with Major Livestock Waste Type. *African Journal of Agricultural Research* **2009**, *4*, 571–577.
10. Fantozzi, F.; Buratti, C. Biogas Production from Different substrates in an Experimental Continuously Stirred Tank Reactor

anaerobic digester. *Bioresource Technology* **2009**, *100*, 573–5789, https://doi.org/10.1016/j.biortech.2009.06.013.
11. Neves, L.; Oliveira, R.; Alves, M.M. Influence of Inoculums Activity on the Bio-methanization of a kitchen Waste Under Different Waste/inoculum Ratios. *Process Biochemistry* **2004**, *39*, 2019–2024, https://doi.org/10.1016/j.procbio.2003.10.002.
12. Amon, T.; Amon, B.; Kryvoruchko, V.; Machmüller, A.; Hopfner-Sixt, K.; Boriroza, V.; Hrbek, R.; Friedel, J.; Pötsch, E.; Wagentristel, H.; Schreiner, M.; Zollitsch, W. Methane production through anaerobic digestion of various energy crop grown in sustainable crop rotations. *Bioresource Technology* **2007**, *98*, 3204–3212, https://doi.org/10.1016/j.biortech.2006.07.007
13. Kashyap, D.R.; Dadhich, K.S.; Sharma, S.K. Bio methanation under Psychrophilic Conditions: a review. *Bioresource Technology* **2009**, *87*, 147–153, https://doi.org/10.1016/S0960-8524(02)00205-5.
14. Bond, T.; Templeton, M.R. History and future of domestic biogas plants in the developing world. *Energy Sustainable Development* **2011**, *15*, 347–54, https://doi.org/10.1016/j.esd.2011.09.003.
15. Misi, S.N.; Froster, C.F. Batch co-digestion of multi-component agro-wastes. *Bioresource Technology* **2001**, *76*, 165–168, https://doi.org/10.1016/S0960-8524(01)00078-5.
16. Faaij, A.P.C. Bio-energy in Europe: changing technology choices. *Energy Policy*, **2006**, *34*, 322–342, https://doi.org/10.1016/j.enpol.2004.03.026.
17. Habiba, L.; Hassib, B.; Moktar, H. Improvement of activated sludge stabilization and filterability during anaerobic digestion by fruit and vegetable waste addition. *Bioresource Technology* **2009**, *100*, 1555–60, https://doi.org/10.1016/j.biortech.2008.09.019.
18. Nayak, A.; Bhushan, B. An overview of the recent trends on the waste valorization techniques for food wastes. *Journal of Environmental Management* **2019**, *233*, 352–370, https://doi.org/10.1016/j.jenvman.2018.12.041.
19. Garcia Pena, E.I.; Parameswaran, P.; Kang, D.W.; Canul-Chan, M.; Krajmalnik-Brown, R. Anaerobic digestion and co digestion of vegetable and fruit residues: process and microbial ecology. *Bioresource Technology* **2011**, *102*, 9447–9455, https://doi.org/10.1016/j.biortech.2011.07.068.
20. Deshpande, N.V.; Kale, N.W.; Deshmukh, S.J. A study on Biogas generation from Mahua (Madhucaindica) and Hingan (Balanitesaegyapytiaca) oil cake. *Journal of Energy for Sustainable development* **2012**, *16*, 363–367.
21. Poggi-Varaldo, H.M.; Gómez-Cisneros, E.; Fernández-Villagómez, G.; Esparza-García, F.; Rinderknecht-Seijas, N. Aerobic post-composting of digestates from anaerobic digestion of paper mill sludge and the organic fraction of municipal wastes, Barcelona, Spain. **1999**, *1*, 258–265.
22. Carucci, G.; Carrasco, F.; Trifoni, K.; Majone, M.; Beccari, M. Anaerobic digestion of food industry wastes: effect of codigestion on methane yield. *Journal of Environmental Engineering-ASCE* **2005**, *131*, 1037–1045, https://doi.org/10.1061/(ASCE)0733-9372(2005)131:7(1037).
23. Hobbs, S.R.; Landis, A.E.; Rittmann, B.E.; Young, M.N.; Parameswaran, P. Enhancing anaerobic digestion of food waste through biochemical methane potential assays at different substrate: inoculum ratios. *Waste Management* **2018**, *71*, 612–617, https://doi.org/10.1016/j.wasman.2017.06.029.
24. Zhang, L.; Lee, Y.; Jahng, D. Anaerobic co-digestion of food waste and piggery wastewater: focusing on the role of trace elements. *BioSource Technology* **2011**, *102*, 5048–5059, https://doi.org/10.1016/j.biortech.2011.01.082.
25. Kumar, M.; Ou, Y.L.; Lin, J.G. Co-composting of green waste and food waste at low C/N ratio. *Waste Management* **2010**, *30*, 602–609, https://doi.org/10.1016/j.wasman.2009.11.023.
26. Zhu, N. Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. *Bioresource Technology* **2007**, *98*, 9–13, https://doi.org/10.1016/j.biortech.2005.12.003.
27. Appels, L.; Baeyens, J.; Degreve, J.; Dewil, R. Principles and potential of the anaerobic digestion of waste-activated sludge. *Progress in Energy and Combustion Science* **2008**, *34*, 755–781, https://doi.org/10.1016/j.pecs.2008.06.002.
28. Nagao, N.; Tajima, N.; Kawai, M.; Niwa, C.; Kurosawa, N.; Matsuyama, T.; Yusoff, F.M.; Toda, T. Maximum organic loading rate for the single-stage wet anaerobic digestion of food waste. *Bioresource Technology* **2012**, *118*, 210–218, https://doi.org/10.1016/j.biortech.2012.05.045.
29. Li, Y.; Yan, X.L.; Fan, J.P.; Zhu, J.H.; Zhou, W.B. Effects of mixture ratio on anaerobic co-digestion with fruit and vegetable waste and food waste of China. *Journal of Environmental Science* **2011**, *23*, 1403–1408, https://doi.org/10.1016/S1001-0742(10)60572-4.
30. Ghaniyari-Benis, S.; Borja, R.; Bagheri, M.; Monemian, S.A.; Goodarzi, V.; Tooyserkani, Z. Effect of adding nitrate on the performance of a multistage biofilter used for anaerobic treatment of high-strength wastewater. *Chemical Engineering Journal* **2010**, *156*, 250–256, https://doi.org/10.1016/j.cej.2009.10.012.
31. Kaparaju, N.L.P.; Rintala, J.A. Thermophilic Anaerobic Digestion of Industrial Orange Waste. *Environmental Technology* **2006**, *27*, 623–633, https://doi.org/10.1080/09593332708618676.
32. Nopharantana, A.; Pullammanappllil, P.C.; Clark, W.P. Kinetic and Dynamic Modeling of Batch Anaerobic Digestion of Municipal Solid Waste in a Stirred Reactors. *Waste Management* **2007**, *27*, 595–603, https://doi.org/10.1016/j.wasman.2006.04.010.
33. Boe, K. *Online Monitoring and Control of the Biogas Process.* Doctoral thesis, Institute of Environment & Resources, Technical University of Denmark, 2006.
34. Das Neves, C.G.; Rimstad, E.; Tryland, M. Cervidherpesvirus 2 causes respiratory and fetal infections in semidomesticated reindeer. *Journal of clinical Microbiology* **2009**, *47*, 1309–1313.
35. Shah, B.V. SUDAAN User's Manual, Release 7.5. Research Triangle Park: Research Triangle Institute, 1997.
36. Ye, M.; Liu, J.; Ma, C.; Li, Y.Y.; Zou, L.; Qian, G.; Xu, Z.P. Improving the stability and efficiency of anaerobic digestion of food waste using additives: A critical review. *Journal of Cleaner Production* **2018,** *192*, 316–326, https://doi.org/10.1016/j.jclepro.2018.04.244.
37. Shanmugam, S.R.; Adhikari, S.; Nam, H.; Kar Sajib, S. Effect of bio-char on methane generation from glucose and aqueous phase of algae liquefaction using mixed anaerobic cultures. *Biomass and Bioenergy* **2018**, *108*, 479–486, https://doi.org/10.1016/j.biombioe.2017.10.034.
38. Kainthola, J.; Shariq, M.; Kalamdhad, A.S.; Goud, V.V. Enhanced methane potential of rice straw with microwave assisted pretreatment and its kinetic analysis. *Journal of Environmental Management* **2019**, *232*, 188–196, https://doi.org/10.1016/j.jenvman.2018.11.052.

6. ACKNOWLEDGEMENTS

We are most grateful to Ryon Biogas energy to supporting pilot study specially Mr. Shabbir Rehman for his special gratitude, efforts and guidance. Besides, all authors also appreciated the mess worker of COMSATS IT, Abbottabad for their valuable support and cooperation during collection of data. We also Highly acknowledge the efforts of Hasnian Shah, Madam Saima zaib and Fayaz Shah during laboratory work. In last, special thanks to my beloved sister Marium sardar to help me during the quantification of kitchen waste and make this study possible.