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Characterization of food wastes from the hotel industry as a potential feedstock for energy production

Emily Machuma Muchele [a], Booker Osodo [a], Isaiah Omosa [b], Emmanuel Yeri Kombe [a,*]

[a] *Department of Energy, Gas and Petroleum Engineering, Kenyatta University, P.O. BOX 43844-00100, Nairobi, Kenya*
[b] *Department of Civil Engineering, Kenyatta University, P.O BOX 43844-00100, Nairobi, Kenya*

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ABSTRACT

Food waste contribute to 38% of total Municipal Solid Wastes (MSW) in Kenya and end up in landfills. Due to high competition in the available space, most cities, including Nairobi, do not have enough space for landfills. Therefore, there is a need for efficient ways to manage the generated waste. Developed countries have embraced Waste-to-Energy technologies, minimizing waste generation and converting generated waste into energy and other resources. Waste characterization is a key element in the energy generation process not only to identify important parameters but also to guide biomass source segmentation. In this study, food wastes were collected from 21 hotels within Nairobi City County, in different mixed ratios and subdivided into five samples for investigation and analysis. The average feedstock characteristics were observed to be moisture content (6.0%, $p < .001$, $R^2 = 90.70$ %), total solid (93.7%, $p < .001$, $R^2 = 99.97$ %), volatile solid (84.3%, $p < .001$, $R^2 = 99.80$ %), ash content (4.2%, $p = .005$, $R^2 = 48.54$ %), fixed carbon (5.4%, $p < .001$, $R^2 = 88.61$%), nitrogen (3.6%, $p = .04$, $R^2 = 36.81$ %), carbon to nitrogen ratio C/N (4.0), crude protein (22.4%, $p = .004$, $R^2 = 49.36$ %), crude lipids (12.1%, $p < .001$, $R^2 = 89.06$ %), total organic carbon (44%, $p < .001$, $R^2 = 94.70$%), potassium (0.6%), sodium (1.2%), calcium (0.2%), and phosphorus (0.4%). The potassium, sodium, calcium and phosphorus p and R^2 values all calculated together were $p < .001$ and $R^2 = 72.35$%. The results showed a significant difference in the means of the samples with the majority of the parameters registering a strong positive correlation of above 50%. The analysis revealed that the feedstock under investigation contained well-balanced parameters for briquette, biogas, syngas and biochar production. Therefore, the findings of this research provide vital knowledge in integrating energy production from food wastes thereby improving the efficiency of food waste utilization.

1. Introduction

1.3 billion tons of food is lost globally as wastage of food occurs at all levels of the food supply system, including during farming, transportation, retailing, processing, cooking, and consumption [1]. Food waste generates approximately 4.4 gigatonnes of carbon dioxide (CO_2), or 8% of total greenhouse gas (methane, nitrous oxide, ammonia, hydrogen sulfide etc.) emissions [2]. This is because food waste contributes 38% of Municipal Solid Waste (MSW) in cities around the world, which ends up in landfills [3]. The resource-intensive issue of waste management has become more complex as the waste collection and disposal service is not keeping pace with the rapid urban population growth, especially in African Cities. The rapid urban population growth accelerates the establishment of facilities like hotels used not only for accommodation but also for other activities such as workshops and conferences.

The hotel industry generates significant CO_2 emissions during the production, transportation, and handling of food. 45% of food waste in the hotel industry is generated through food preparation and production processes, followed by food left on customer plates at 34% while 21% of food spoilage is through poor storage [4]. Food waste disposed in landfills generate methane, a greenhouse gas that worsens the climate change crisis [2,3].

Developing countries like Kenya struggle with the environmental pollution challenges associated with the generation of food waste from the hotel industry [5]. This contributes to the devastating effects of climate change [6] as food waste decomposes in landfills causing massive layers of organic waste that produce heat-trapping greenhouse

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* Corresponding author.
E-mail address: kombe.emmanuel@ku.ac.ke (E.Y. Kombe).

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gases (GHGs) [7]. The emissions of these gases result in the climate change crisis which causes floods, drought, food shortage, renewable energy challenges, water scarcity, and diseases, among others [8]. In as much as solutions have been devised to curb the crisis, energy production from food waste has been given little attention in Kenya. There is a need for urgent measures for hotels to not only manage the environment but also to reduce their energy costs by offsetting their energy requirement using energy generated from food waste [9,10].

Physical, biological and thermal waste-to-energy conversion technologies have been widely applied to address issues of organic waste management in urban areas, industries and households [10], as well as overcoming energy insecurity challenges. For a sustainable waste-to-energy production system, feedstock characterization is critical in evaluating waste's potential as a feedstock for different conversion technologies.

Food waste characterization studies have been undertaken to achieve various objectives in energy production processes. For instance, Singh et al. [11] characterized food waste for a low-temperature gasification process while Slopiecka et al. [12] characterized food waste to improve its use in anaerobic digestion plants. Suarez et al. [9] characterized food, garden and park waste for energy recovery through anaerobic co-digestion and hydrothermal per-treatment while Abdelaal et al. [13] characterized food waste from a University campus to determine its potential for energy recovery. Their findings are as per Table 1.

An extensive literature survey showed that little information is available on the presence of potassium, calcium, sodium, barium and phosphorus which are critical in establishing the feedstock sustainability and efficiency of an energy production system.

Since organic composition and other factors like pH, carbon to nitrogen ratio (C/N), and total organic carbon (TOC) vary with the region, season as well as processing characteristics, there are minimal studies on the characterization of post-consumer food wastes from the hotel industry in Nairobi City County, Kenya. The present study reports a detailed characterization of various food waste streams generated from commercial hotels in Nairobi City County, Kenya, with the aim of assessing their potential for use in energy production through physical, biological and thermal waste-to-energy conversion technologies. The influence of various parameters on briquette, biogas, syngas and biochar production was analyzed. The findings of this research provide the basis for the efficient utilization of various food waste streams for energy recovery which would consequently solve challenges of energy insecurity, waste disposal and environmental management in the hotel industry.

2. Theoretical approach

To evaluate the potential utilization of food waste for energy generation, some characterization parameters were studied based on the Association of Official Analytical Chemists (A.O.A.C) International Standard Methods. They include moisture content (MC), pH, total solids (TS), volatile solids (VS), fixed carbon (FC), total organic carbon (TOC), and ash among others.

Table 1
Food waste characterization studies.

Parameter	References			
	[13]	[11]	[9]	[12]
pH	-	-	-	5.88
Moisture Content (MC) (%)	-	11.312	-	-
Total Solid (%)	32.5	-		64.84
Volatile Solid (%)	85.9	73.262	67.6	44.18
Ash (%)	6.0	3.304	11.8	-
Fixed Carbon (%)	8.1	12.122	13.3	-
Nitrogen (%)	3.4	2.89	1.9	-
C/N	-	-	-	15.9
Crude Protein (%)	-	-	-	15.59
Crude Lipids (%)	-	-	-	19.05
Total Organic Carbon (%)	49.3	45.23	44.5	39.5
Sulphur (%)	-	-	0.2	-
Hydrogen (%)	7.0	6.92	6.2	-
Oxygen (%)	34.2	44.96	35.4	-

The MC can be defined as the amount of water that evaporates when a feedstock is dried at a constant temperature of 105 °C [14]. It lies between 50% and 80% of water by the dry weight of the food waste [15]. Once the moisture is removed, Total Solid remains [16]. The MC and TS are determined using equations 2–1 and 2–2 respectively [17].

$$\%\ Moisture\ Content\ (MC) = \frac{Dry\ weight\ at\ 60\ o_C - Dry\ weight\ at\ 105\ o_C}{Dry\ weight\ at\ 60\ o_C} * 100 \tag{2–1}$$

$$\%\ Total\ Solid\ (TS)\ =\ 100\ -\ MC\ \% \tag{2–2}$$

The Ash content of a feedstock facilitates the determination of VS. The ash, VS and FC are expressed using equations 2–3, 2–4 and 2–5, respectively [14,18].

$$\%\ Ash\ =\ \frac{t-u}{s-u} * 100 \tag{2–3}$$

Where: t = crucible + ash (after ashing); s = Crucible + Sample; u = Empty Crucible

$$\%\ Volatile\ Solids\ (VS) = \frac{Total\ Solid\ weight\ (g) - Ash\ weight\ (g)}{Total\ Solid\ weight\ (g)} * 100 \tag{2–4}$$

$$\%\ FC\ (wet\ basis)\ =\ 100\ -\ \%\ MC\ -\ \%\ VS\ -\ \%\ Ash \tag{2–5}$$

Based on the Soxhlet Extraction and Total Kjeldahl Nitrogen (TKN) methods, lipids, nitrogen and protein content in the feedstock are determined using equations 2–6, 2–7 and 2–8, respectively [19]:

$$\%Lipid = \frac{weight\ of\ flask\ with\ extracted\ lipid\ (g) - weight\ of\ empty\ flask\ (g)}{Sample\ weight\ (g)} * 100 \tag{2–6}$$

$$Nitrogen(\%) = \frac{14 * (Titre - blank) * 50mL * Q * \mathrm{H2SO4} * 100}{1000 * 10mL * Sample\ weight)} \tag{2–7}$$

$$\%\ Protein\ =\ \%\ Nitrogen * 6.25 \tag{2–8}$$

3. Materials and methods

3.1. Study area description

The study was undertaken in Nairobi City County which is one of the 47 counties of Kenya. Nairobi is a multicultural and cosmopolitan city [18], with a population of 4397,073 residents, a population density of 6247 people per km^2 and an annual growth rate of 4.1% according to the 2019 census. Located at 36.82 ^{o}E longitude and -1.28 ^{o}S.

3.2. Collection and preparation of substrate

About 230 kg of food wastes were collected from 21 hotels in Nairobi City County. Physical sorting of wastes to remove non-food wastes resulted in five batches of different mixed ratios in 50kg containers each representing a sample. The different compositions of five samples were as follows: **Sample 1**: Rice, cabbages, macaroni, watermelon, and chicken; **Sample 2**: Rice, beans, potato wedges, kales, beef, and pineapple; **Sample 3:** Spaghetti, carrots, eggplants, fish, spinach, and eggs; **Sample 4:** Maize, pigeon peas, rice, beef, carrot, and sweet potatoes; and

Sample 5: Matoke, beef, cabbages, cowpeas and spinach. Each group of food wastes per sample was mixed by hand, and then manually mashed before being scooped into an approximately 1 kg container in preparation for further homogenization and laboratory analysis.

3.3. Determination of the physical and biochemical characteristics

3.3.1. Preparation

Wet samples were each weighed and then mashed independently using a pestle and mortar to homogenize them into five pastes-based samples. Sample solutions for pH determination were prepared from the pastes before drying the remaining in an oven at 60 °C for 48 hours as per [20]. This was to remove absorbed water during cooking. Reweighing was performed at 60 °C and 105 °C and readings recorded. The dried samples were ground using a kitchen grinder and the powdered samples placed in a desiccator until all determinations for the remaining parameters were completed while the untreated samples were refrigerated at -20 °C. All experiments were carried out in the Chemistry laboratories at Kenyatta University and the University of Nairobi, located in Kiambu County and Nairobi City County, Kenya respectively. The analysis was done in triplicate.

3.3.2. Sample analysis

Table 2 summarizes the methods and types of equipment used for the analysis of the chemical composition of food waste. The overall characteristics of food wastes from the hotel industry in Nairobi were determined in triplicate for each of the five samples, and the average per sample calculated. Analysis of Variance (ANOVA) was computed in Minitab 18 software to investigate the central tendency and dispersion measures for the parameters' percentage composition.

Table 2
Food waste characterization equipment and methods for this study.

Parameter	Method & Equipment	Justification	Reference
Alkalinity/ Acidity	pH Measurement using pH meter (Code: HI9125; Serial number: D0029975)	A method used to determine acidity or alkalinity of a sample	[18,20]
Moisture content, Total Solids, Volatile Solids, Fixed carbon and Ash	Proximate analysis using crucibles, desiccators, muffle furnace, blender/ grinder , Magnetic stirrer, Analytical balance and Laboratory oven	Application of standard formulae for calculation of the parameters	[21–23]
Lipids	Soxhlet extraction using A 250 mL 24 40 glass Soxhlet Extractor 40 38 Graham Coil condenser one reservoir flask with a 250 mL, 180 W, AC220V/50P, Model No. ZDHW UMS-UK	Due to its automatic process repeatability and hybrid continuous-discontinuous characteristics.	[24]
Nitrogen and Proteins	Total Kdjedial Nitrogen (TKN) using Kjeldahl Protein Apparatus (Serial number : TP2017330715)	Easily determines macro-nutrients like crude proteins in food	[25,24]
Potassium, Sodium, Calcium, Barium and Lithium	Flame Photometry using PFP7 Clinical Flame Photometer	It is ideal for high through-put application as it continuously analyzes the sample stream.	[26,27]
Total Organic Carbon	Colorimetric Method with Potassium dichromate and sucrose standards using Spectrophotometer (Model no: U-2900)	Offers a wide range of applications including laboratory research. Its ability to measure the absorbance of light of different wavelengths as it moves through a specific liquid sample.	[28,29]
Phosphorus and Sulfur	U-V spectrophotometer (Model no: BK-UV1200)	High accuracy during experiments as it has the ability to identify composition, including physical and chemical properties of the sample based on interaction between Ultra-Violet light and sample.	[30]

4. Results and discussion

4.1. Weight and pH of food waste samples

Fig. 1 shows the weight and pH of food waste samples. The weight ranged from 183.6 g to 214.2 g wet and 52.3 g to 58.1 g dry weight respectively as shown in Fig. 1 (a). These results are within the range provided by global laboratory sampling statistics of 10 g - 300 g samples in food waste characterization studies, hence making them significant [31]. The significant difference between wet and dry weight for this study depicts a high rate of water absorbency during cooking.

From Fig. 1 (b), it can be observed that the pH of the food waste samples ranged from 4.7 to 5.8, with an average pH of 5.3. In the physical energy conversion process, Suhartini et al. [32] indicated that food wastes with low pH and high carbohydrates would be very effective in making briquettes. This implies that the food wastes under investigation is a potential feedstock for the briquette-making. During the fermentation processes, occurrence and microorganism distribution are highly influenced by the pH. A pH range of 3–4 is optimal for the growth of acidophile, neutrophile and alkaliphile microbes. The function and composition of these microbial communities would be shaped by the pH as it can affect the kinetics and thermodynamics of microbial respiration [33]. pH has a significant effect on the anaerobic digestion process, with the optimum pH ranging from 5.0–8.0 [12]. This makes samples 2, 3, 4, and 5 favorable feedstocks for anaerobic digestion, such as applied in the production of biogas, bioethanol etc.

4.2. Influence of moisture content (MC) on energy production

Fig. 2 illustrates the influence of MC of food waste samples on energy production. It was observed that the dry food wastes in Sample 2 registered the lowest MC at 5.1% while sample 5 had the highest MC at 6.51%. From the error bars, the results revealed a significant difference in the means of the samples.

In physical bioconversion processes, one is advised to control the MC within the limits of 10% if high-quality and durable briquettes are to be manufactured. Nikiema et al. [34] noted that efficient fuel and good-quality briquettes are dependent on low moisture content ranging from 6 % to 14 %.

In as much as low moisture content favors physical and thermal waste-to-energy conversion technologies, it is obviously the opposite in biological processes. The efficiency and stability of an anaerobic digestion (AD) process are highly dependent on a high moisture content of 54–87% [35] on a wet basis; and 60–75% dry AD. Regarding the current study, sample 5 makes a good substrate for anaerobic co-digestion due to its high moisture content of 35% to 67% on a wet basis. However, sample 2 would favour gasification processes due to its low moisture content of 6% to 10% on a dry basis.

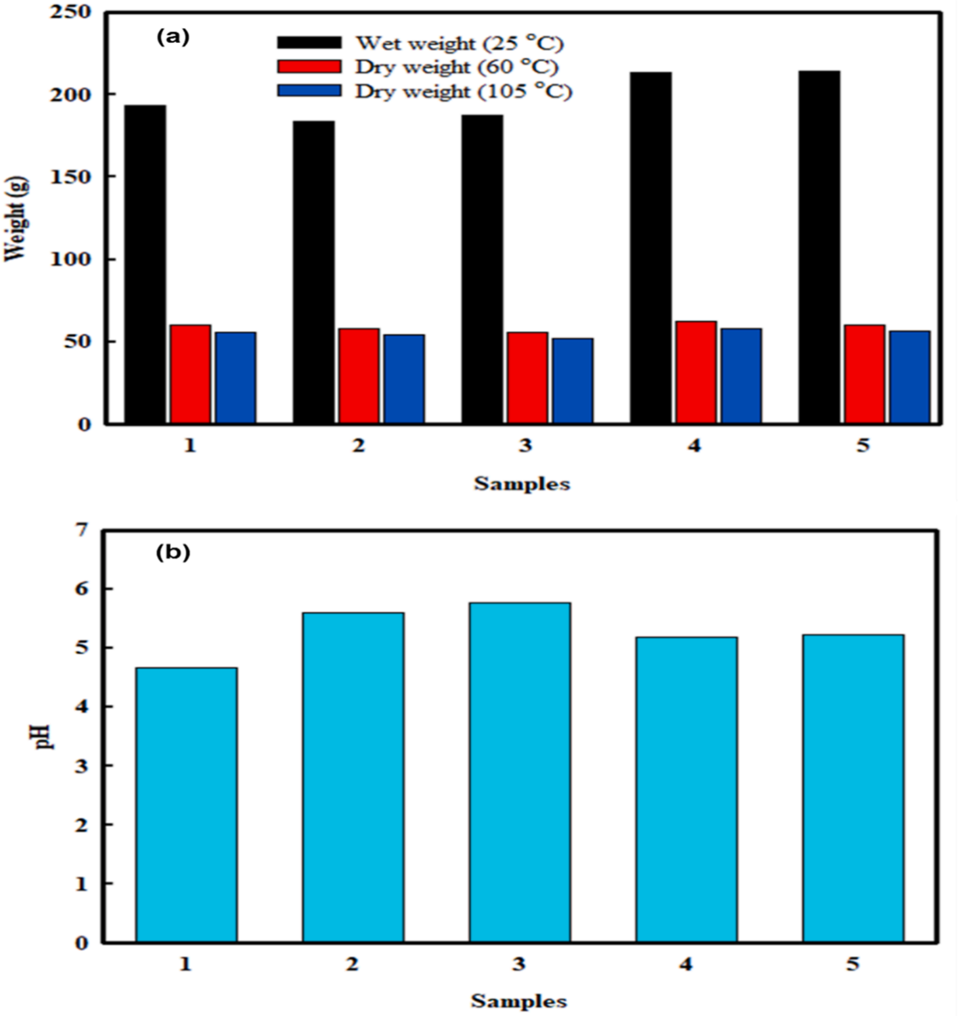

Fig. 1. Weight and pH of samples.

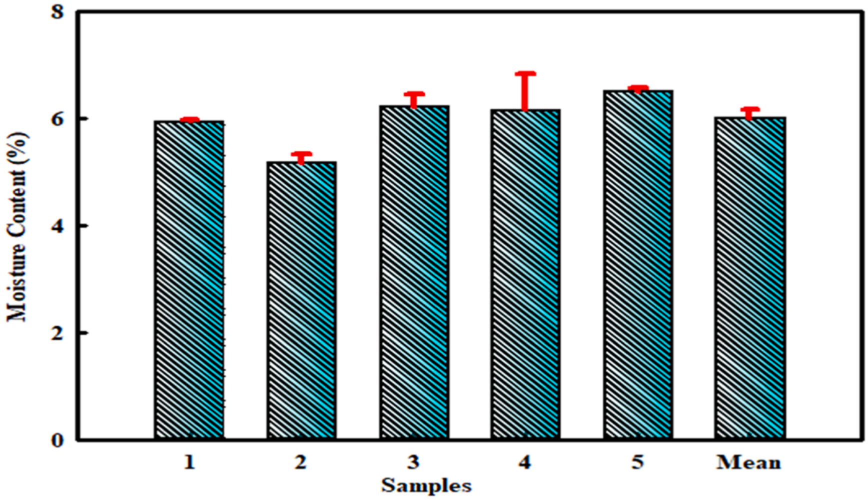

Fig. 2. Moisture Content results.

4.3. *Influence of total solids (TS) and volatile solids (VS) on energy production*

Fig. 3 illustrates the impact of TS and VS on energy production. The total and volatile solids were observed to range from 93.23 - 94.06% and 81.57 - 86.86% as shown in Figs. 3 (a) and (b), respectively.

A statistically significant difference in the means for TS and VS was observed as depicted from the error bars. Total solids are among the many factors that contribute to the density and yield of briquettes as this process involves the compression of feedstock into a uniform solid unit.

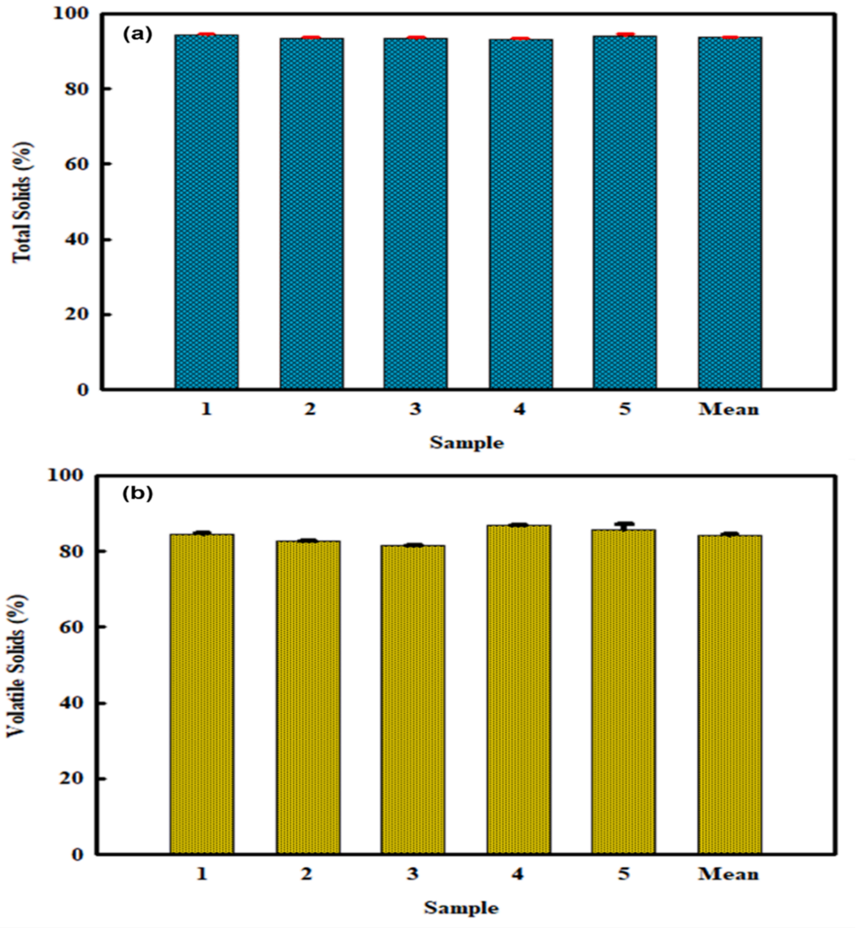

Fig. 3. Total and Volatile solid results.

The available surface area of briquettes is a reflection of the bulk density of ground feedstock which depends on the particle size as well as particle distribution. High total solid enhances the surface area optimizing the quantity of briquettes [36]. Depending on the feedstock composition, briquettes with high volatile matter of 50–90% can ignite easily but could have low heating value [37]. Total solid is a key parameter in biomethane production performance which is affected by organic reductions that are correlated with volatile solids [38]. This reveals that total solid determines the organic matter that biodegrades during anaerobic digestion. The parameters are also very important during co-digestion processes as their ratios could affect the yield.

The observed volatile solids range of 81.57% to 86.86% is within the recommended range of 50–90% for bio-energy conversion processes [34]. In thermal waste-to-energy conversion processes, total and volatile solid parameters are found to be critical in synthetic gas (syngas) generation. The biofuels (biogas, biohydrogen, biomethane) production rate and potential are dependent on the concentration of total and volatile solids of the feedstock among other factors [25]. In consideration of other factors like operating pH, hydraulic retention time, organic loading rate, digester design etc., this study indicates that high volumes of biogas would be produced from sample 4. In addition, digester feedstock's organic matter can be monitored by the ratio of volatile and total solids. The fraction of biodegradation would be represented by volatile solids while the rate of digestion process would be represented by the total solids. Food wastes in the current study had a 0.9 VS/TS ratio; or 90% digestion rate. This increases the potential of biogas production as observed by Slopiecka et al. [39].

4.4. Influence of ash and fixed carbon on energy production

Fig. 4 illustrates the effect of ash and fixed carbon on energy production. Fig. 4 shows a minimal presence of solid residue (ash and fixed carbon) ranging from 2.25% - 7.32% and 9.73% - 14.82% respectively. Fig. 4 (a) highlights how sample 3 dispersed from other samples indicating a statistically significant difference in their means. The same trend is observed by sample 5 in Fig. 4 (b) revealing a high significant difference in their means.

With fixed carbon ranging from 9% to 25%, and ash less than 4%, Nikiema et al. [34] observed that food waste could have great potential in energy production as this indicates a high volume of syngas generation at temperatures above 550 °C. There is an occasional wide range of variation of ash and fixed carbon with a coefficient of variation above 50% as seen in samples 1 and 3. A similar trend is observed by Pour et al. [40] indicating the heterogeneous nature of food wastes from the hotel industry.

4.5. Influence of nitrogen and total organic carbon (TOC) on energy production

Fig. 5 illustrates the effect of nitrogen and total organic carbon on energy production. Fig. 5 (a) indicates the presence of nitrogen in various food samples, ranging from 1.8% to 6.9%.

The figure shows that sample 2 had the highest amount of nitrogen at 6.9% while sample 1 had the least at 1.8%. Due to its inert nature, nitrogen from organic matter can be used as a 'green' corrosion inhibitor by displacing oxygen in wet parts of the plant through purging [41]. Nitrogen is also an important soil and sediment component as it can be

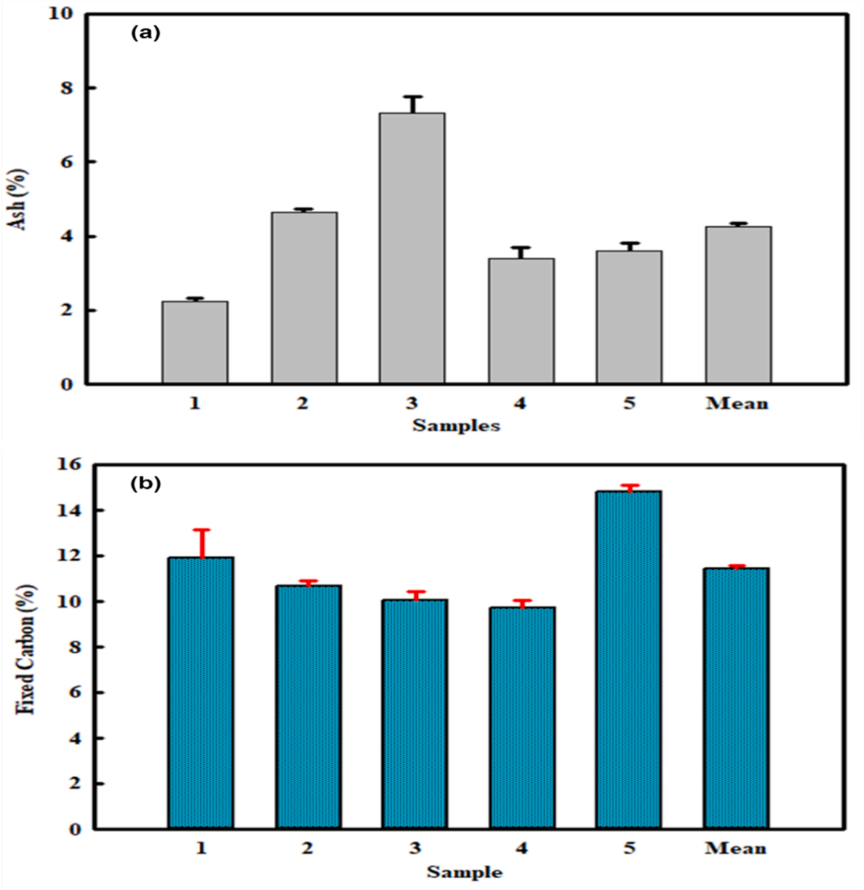

Fig. 4. Ash and Fixed Carbon results.

used to differentiate terrestrial and marine organic matter sources, depositional conditions of the environment, indices of pollution, indicators of productivity and quality of the soil [42]. These results are also important in feedstock supply as fertile areas could be segmented for agriculture utilization resulting in more feedstock for biofuel production. In the nitrogen economy, sample 2 would be favourable for conversion into nitrogen-based fuels like ammonia which can be used for high-pressure gas generation and means of energy storage [43].

Fig. 5 (b) depicts the presence of TOC in the samples ranging from 36.57% to 51.6%. Percentage variation of TOC can be used to control and evaluate the formation of biogas during the fermentation process. TOC of 41- 44% can give a higher biogas yield during the fermentation process as observed by Paranhos et al. [44]. From the error bars, the results revealed a significant difference in the means of the samples.

4.6. *Influence of Carbon to Nitrogen (C/N) ratio on energy production*

Fig. 6 shows the effect of carbon-to-nitrogen ratio on energy production. The C/N ratios for the samples ranged from 1.5 to 6.8. A balanced carbon-to-nitrogen ratio is an important parameter to optimize biogas production. It determines the stability and composition of microbes in anaerobic digestion. When an organic material has a C/N ratio between 1 and 15, mineralization occurs rapidly availing nitrogen for plant uptake [45].

It is observed that an inadequate C/N ratio could hinder microbial activity during organic matter degradation into biogas, as high a C/N ratio indicates inadequate nitrogen for the cell functions limiting the growth of fermentation bacteria thereby reducing biogas production [46]. For efficient biogas production, it is recommended that the C/N ratio be maintained between 20 and 35 to maximize the efficiency of a bio-digester. For instance, a 60% increase in biogas generation could be achieved by feedstock co-digestion where carbon-rich feeds like potato waste (C/N ratio 35) are co-digested with nitrogen-rich feeds like beet leaf (C/N ratio 14) [47]. It can be deduced from Fig. 6 that sample 1 would be a good feedstock for co-digestion with sample 2 to increase biogas production to approximately 30%. From the error bars, a significant difference in the means of the samples was observed.

4.7. *Influence of crude proteins and lipids on energy production*

Fig. 7 shows the effect of crude proteins and lipids on energy production. Fig. 7 (a) shows the presence of crude proteins ranging from 11.36% to 43% in various food waste samples. It was observed from Fig. 7 (a) that sample 2 mean was significantly different from other samples. Similarly, Fig. 7 (b) shows the significant difference between the means of sample 3 and 5.

Great potential to upcycle anaerobic digestion effluents into protein-rich biomass has already been observed by Khoshnevisan et al. [48] through fermentation of two protein-rich microorganisms (methane and hydrogen oxidizing bacteria). It is also evident that lipid-based biofuels have high energy density as compared to other biofuels, making them more compatible with the existing infrastructure [49]. The performance of these lipid-based biofuels can be enhanced through adjustment of the chemical composition of the feedstock as observed by Wang et al. [50]. Crude lipids account for biological hydrogen generation by dark fermentation even if the yield is less as compared to carbohydrate-rich substances [51].

4.8. *Influence of potassium, sodium, calcium and phosphorus on energy production*

Fig. 8 shows the influence of potassium, calcium and phosphorus on

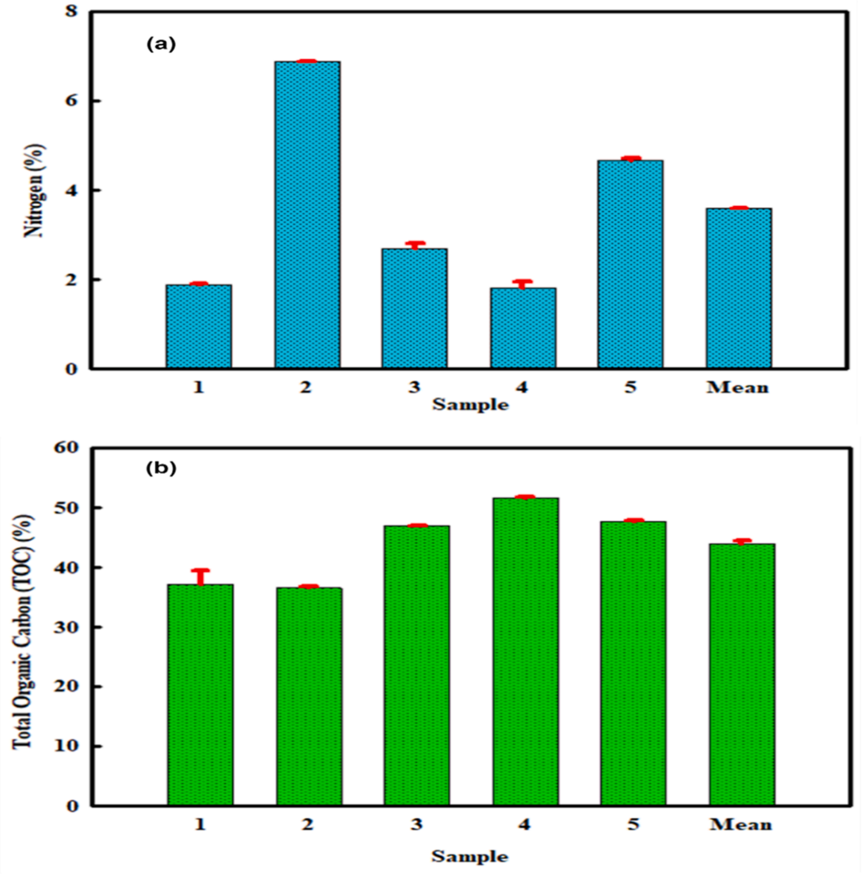

Fig. 5. Nitrogen and Total Organic Carbon results.

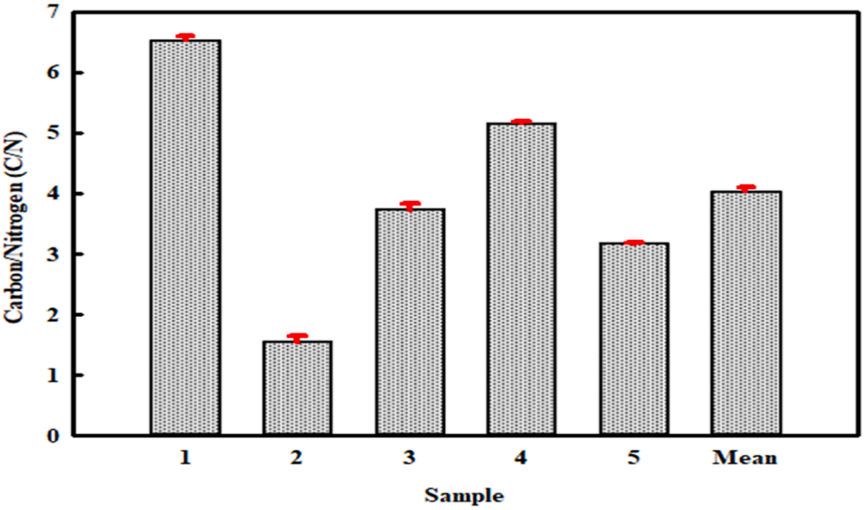

Fig. 6. Carbon to Nitrogen ratio results.

energy production. The minute presence of potassium in food waste samples ranged from 0.2% to 1.56%, the lowest being from sample 3 while the highest being from sample 2. A statistically significant difference in the various groups can be observed from the error bars.

Low levels of potassium, as shown in this study (0.2–1.56%), would be linked to the alkaline content in food waste that is highly volatile at the combustion and gasification process as observed by Knutsson et al. [52]. While potassium in its limited content promotes catalytic effect during the gasification process [53], it also consumes volatile fatty acids, improving biodegradation of protein-rich components, and enhancing dehydrogenation. This improves anaerobic microorganism viability and morphology [54]. Breakdown of short-chain fatty acids increasing microbial activities during hydrolysis in anaerobic digestion is enhanced by Calcium peroxides (CaO_2) improving biogas generation [55,56].

From Fig. 8, sodium content in the food waste ranged from 1.0% to 1.3 %. Sodium could be utilized to obtain Sodium Chloride (NaCl), popularly known as common salt, which is important in bioenergy production. Its levels could be controlled to maintain the pH in

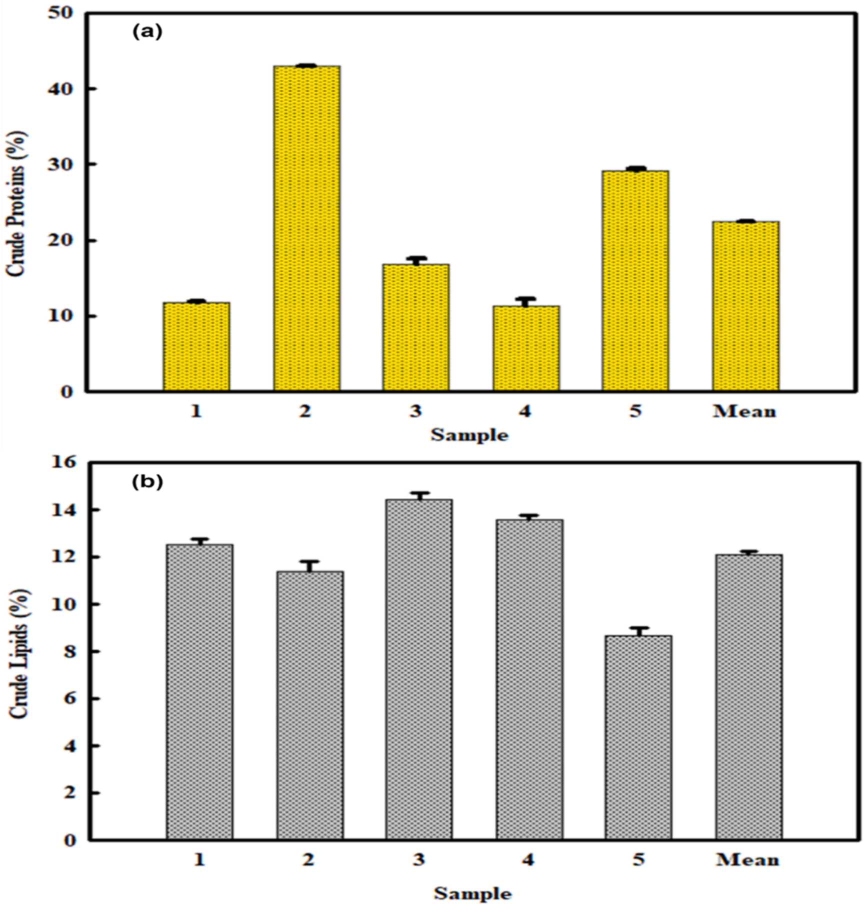

Fig. 7. Crude proteins and lipid results.

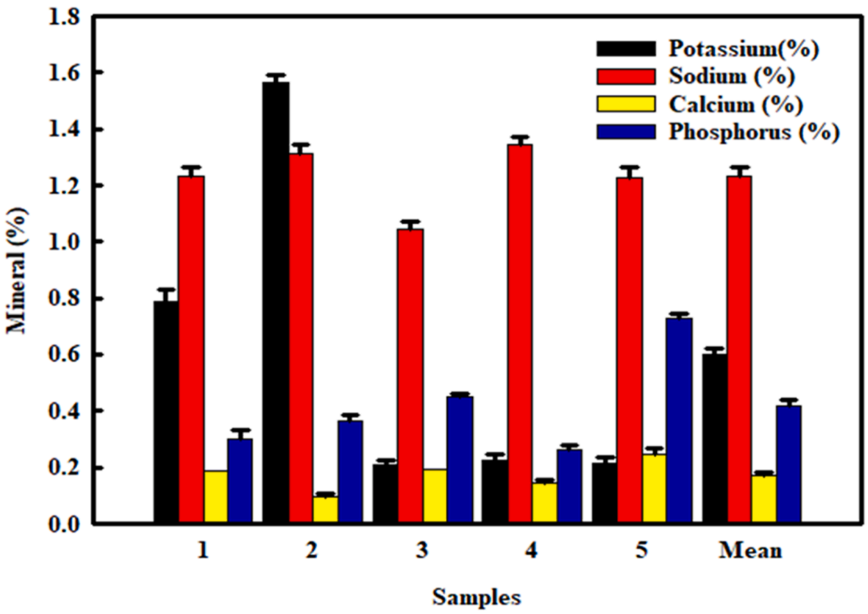

Fig. 8. Potassium, Sodium, Calcium and Phosphorus results.

anaerobic digestion reactions for maximum methane and hydrogen generation [57]. This implies that a suitable addition of sodium during anaerobic digestion would enhance the biogas production rate, increasing the potential of using leftovers as feedstock for anaerobic digestion. During the conversion of food waste into biochar, dioxins are generated by the concentration of salt in various biochar components. High salt concentration impedes energy conversion processes, calling for demineralization to assist in fuel conversion [58]. The demineralization process enhances sodium control and would be faster if sodium chloride (common salt) levels are known as in the current study.

A minimal presence of calcium in various food waste samples ranging from sample 2 (0.0977 %) to sample 5 (0.2487 %) was observed as evident in Fig. 8. Biofuel production would be more catalyzed by sample 5 since it comprises calcium-rich foods [59]. Parra-Orobio et al. [60] observed that calcium concentrations greater than 150 parts per million (ppm) in inoculum improved granulation processes and biogas accumulation. It is also observed that biohydrogen and biomethane gasses increased by 195% and 338 % respectively when 1 g/L and 3 g/L of calcium particles from calcium-rich egg shells were added to the bioreactor [61]. This huge percentage increase has a lot of impact on energy production processes. It is also noted that calcium and sodium components can be decomposed by microorganisms inhibiting harmful effects on the environment which could lead to an energy efficiency that is cleaner and an eco-friendly environment [62].

Fig. 8 also shows the presence of phosphorus in food wastes ranging from 0.26% to 0.73%. Phosphorus plays a fundamental role in industries and in global food and energy production systems. During anaerobic digestion process, the anaerobic digestion process, the digestates' phosphorus content is critical for evaluating the utilization of its fertilizer. Phosphorus plays an important but an unrecognized role in the water-energy-food nexus. Phosphate fertilizers support and sustain renewable biofuels through commercial cultivation of first-generation biofuel crops like wheat, sugarcane and sugar beet for bioethanol production and palm oil, and soybean for biodiesel production [63].

4.9. Analysis of variance (ANOVA) results

Table 3 shows a one-way ANOVA results computed at a 95% Confidence Interval. The results illustrate the statistical significance of differences among the five distinct food waste samples. The *p* values ranged from 0.00 - 0.05 while the R^2 values ranged from 36.81% - 99.97% in the various parameters. These results indicate a statistically significant difference in means of triplicate measurements for each of the five samples with a strong positive correlation. The model was adopted as the majority of the *p* values were < 0.001 and R^2 values were above 50 % influence.

5. Conclusions

Characterization results showed the presence of numerous elements in food wastes which could change with changes in sample composition. Due to the heterogeneous nature of food wastes and statistically significant differences in sample means (Table 3), different percentages of parameters were obtained from five samples containing various types of food wastes. Food wastes from hotels in Nairobi City County can be used for briquette making, biogas, syngas and biochar production, owing to the high percentage of total and volatile solids at 93.7%, and 84.3% respectively. However, the presence of crude proteins (22.2%) and lipids (12.1%) in these wastes inhibit biodegradation processes that would have enhanced anaerobic digestion limiting the rate of biogas generation. The presence of ash (4.2%) and fixed carbon (11.8%) as well as

Table 3
ANOVA results for various parameters.

Analysis of Variance (ANOVA)						Model Summary			
Source	DF	Adj SS	Adj MS	F-Value	P-Value	S	R^2	R^2 (adj)	R^2 (pred)
Moisture Content (%)									
Factor	5	147.40	29.4808	46.80	0.000	0.793694	0.9070	88.76%	85.46%
Error	24	15.12	0.6299						
Total	29	162.52							
Total Solids (%)									
Factor	5	56,413.6	11,282.7	18,394.58	0.000	0.783180	0.9997	99.97%	99.96%
Error	24	14.7	0.6						
Total	29	56,428.3							
Volatile Solids (%)									
Factor	5	45,562.6	9112.53	2390.92	0.000	1.95226	0.9980	99.76%	99.69%
Error	24	91.5	3.81						
Total	29	45,654.1							
Ash (%)									
Factor	5	65.69	13.138	4.53	0.005	1.70342	0.4854	37.82%	19.59%
Error	24	69.64	2.902						
Total	29	135.33							
Fixed Carbon (%)									
Factor	5	641.52	128.304	37.33	0.000	1.85393	0.8861	86.23%	82.20%
Error	24	82.49	3.437						
Total	29	724.01							
Nitrogen (%)									
Factor	5	49.77	9.955	2.80	0.040	1.88665	0.3681	23.65%	1.27%
Error	24	85.43	3.559						
Total	29	135.20							
Crude Proteins									
Factor	5	2881	576.3	4.68	0.004	11.0985	0.4936	38.81%	20.87%
Error	24	2956	123.2						
Total	29	5838							
Crude Lipids (%)									
Factor	5	747.02	149.404	39.06	0.000	1.95577	0.8906	86.78%	82.90%
Error	24	91.80	3.825						
Total	29	838.82							
Total Organic Carbon (%)									
Factor	5	13,520.5	2704.10	103.56	0.000	5.10998	0.9470	93.78%	92.35%
Error	29	757.2	26.11						
Total	34	14,277.8							
Potassium (%), Sodium (%) Calcium (%) and Phosphorus (%)									
Factor	23	122.55	5.3282	10.92	0.000	0.698548	0.7235	65.72%	56.79%
Error	96	46.84	0.4880						
Total	119	169.39							

potassium, sodium, calcium and phosphorus in their small percentages (0.6%, 1.2%, 0.2%, and 0.4%) respectively, show the potential of using food wastes in biochar production.

CRediT authorship contribution statement

Emily Machuma Muchele: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Booker Osodo:** Writing – review & editing, Supervision, Methodology. **Isaiah Omosa:** Writing – review & editing, Supervision, Methodology. **Emmanuel Yeri Kombe:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

There are no known competing financial interests by authors or relationship that is personal that could influence the reported work in this paper

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Data availability

Data will be made available on request.

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