Closing the Loop: Valorization of Market Organic Waste for Bioelectricity Production, and Consequent Use of Composite in Smart Agriculture

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ABSTRACT

Sustainable Solid waste management is a global challenge urgently seeking redress, as the planet struggles with the subsequent effects – climate change, pests and diseases and other socio-economic pressures. This challenge is loudly pronounced in developing countries like Kenya, whose solid waste management systems are at embryonic level and are struggling to contend with the ever-increasing quantities waste, as it is dumped in open dumpsites and causes pronounced pollution of land, water and air.

In this study, fruit waste was obtained from markets in Nairobi city. The waste was miniaturized in a blender and, together with goat rumen from a slaughter house, placed in the anode of an H-shaped one-liter double-chamber microbial fuel cell equipped with carbon graphite electrodes, a salt-bridge made from saturated NaCl, distilled water in the cathodic chamber and the system connected externally to a multi-meter. The voltage and current produced by the system were monitored for 22 days after which the contents of the anode were removed, dried and incorporated into soil where potted maize and beans were allowed to grow. The growth of the plants was monitored, and compared with those grown using commercial fertilizer.

The results obtained showed that the fruit mixture gave an average voltage of 0.159 ± 0.05 V and average current of 0.022 ± 0.006 mA. The power and power density obtained was in the range of (3.047 to 4.038 μW) and (572.4 to 758.5 $\mu W/m^2$) respectively.

The Compost, vermicast and vermiwash obtained showed favorable characteristics of a bio-fertilizer for both the micro and macro nutrients, as the values for the Mg, N, P, K, Mn, Cu, Fe and Zn for the compost were obtained as 1.3 ± 0.2, 8.9±0.1, 32.4±1.4, 0.003±0.0004, 1.8±0.22, ND, 0.17±0.08, 4.85±0.08 and ND g/kg respectively, while those of the vermicast and vermiwash were obtained as: 7.1±0.11, 87.0±3.8, 7.6±0.07, 18.0±0.23, 97.4±11.9, 16.74±0.022, 6.61±0.11, 0.62±0.03 and 0.13±0.0001 g/kg respectively.

When the yield, height, number of leaves and roots as well as the biochemical composition of the leaves of maize and beans grown using vermiwash and vermicast, it was noted that the yield was slightly higher than that of the commercial fertilizer, a factor that means that the vermicompost can be used in place of the commercial fertilizer. The vermicompost, generally, has a greater advantage over commercial fertilizer as it is highly degradable and results to organic and, therefore, healthier crops.

The study has shown that organic waste in Kenya can undergo a closed loop – from the farm through production of electricity back to the farm. Thus, in this study, multiple solutions have been obtained – sustainable solid waste management (with the consequent results including improved human health and climate change mitigation), generation of clean fuel and appropriate food security solutions. We recommend that the viability of the vermicompost be assessed with other crops.

Keywords: Biodegradation; Fruit-Waste; Organic fertilizer; Vermicompost; Vermicast; Vermiwash

1. Introduction

The problem of Solid waste management is worsening globally, especially with the increase in population and industrial activities, necessitating the need to investigate alternative ways of managing solid waste. Heaps of garbage are a health hazard and, they necessitate land for disposal, among other issues. The energy crisis and environmental pollution have in the recent past promoted research on efficient techniques such as environmental-catalysis to generate bio-energy, Land reclamation, climate change mitigation and solid waste management [1]. In most developing countries, most waste is burnt, in an attempt to reduce it, otherwise it is disposed of in heaps (**Fig. 1.1**), making sound solid waste management, a real challenge [2].

Figure 1.1: A heap of fruits waste at Muthurwa market, Nairobi County

In order to reduce environmental harm, promote sustainability, and advance circular economy, waste valorization is attracting enormous scientific and industrial interest. Waste can be recycled into energy, fuels, and other high-value goods.

1.1 Circular Economy: In resource recovery, waste is changed into useful products as new outputs: in this case, waste is converted into renewable energy. [3] stated that reuse and recycling are part of the circular economy in resource recovery when natural resource extraction and waste generation are minimized. Materials and products are becoming more sustainably developed for long-term use. Thus, generating electricity from waste using microbial fuel cells will address waste management, supply renewable energy, alleviate climate change, and revitalize the economy. In this perspective, the current generation will be able to take care of their fundamental requirements while not jeopardizing capacity of upcoming generations to do the same.

The long-term use of inorganic fertilizers without organic supplements damages the soil physical, chemical and biological properties and cause environmental pollution [4]. Heavy use of agrochemicals since the “green revolution” of the 1960s boosted food productivity at the cost of environment and society. It killed the beneficial soil organisms and destroyed their natural fertility, impaired the power of biological resistance’ in crops making them more susceptible to pests and diseases. Chemically grown foods have adversely affected human health.

Environmentally friendly approach of producing high quality organic fertilizer is one of the major concerns of researchers lately. Organic manures act not only as a source of nutrients and organic matter, but also increase size, biodiversity and activity of the microbial population in soil, influence structure, nutrients turnover and many other related physical, chemical and biological parameters of the soil [4]. By the time the organic waste is excreted by the earthworms as vermicasts, it will be rich in nitrogen (N), phosphorus (P) and potassium (K) as well as trace elements depending on the feedstock type used [5]. This environmentally friendly approach and the rising demand of the naturally derived fertilizer have brought the interest of preparing this paper.

1.2 Vermitechnology, also known as ***vermicomposting***, is a process of utilizing earthworms to reduce varied sources of organic waste. It has been defined as "the digestion of organic materials by earthworms to produce excreta, known as casts" [6]. Compost derived from this type of system is known as 'vermicompost' and is presumed to be "a highly nutritive organic fertilizer". It is a mesophilic process that utilizes micro-organisms and earthworms that are active at 10° C to 32° C (not ambient temperature but temperature within the pile of moist organic material). The process is fast as the material passes through the earthworm gut, a significant but not fully understood transformation takes place, whereby the resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators and fortified with pest repellence attributes as well. In short, earthworms through a type of biological alchemy are capable of transforming garbage into "gold" [7-8].

1.3 Earthworms: Various earthworms have been used for vermicomposting and these include Megascolex *Mauritii, Eudrilus Eugeniae, Perionnyx Excavatus, Lampito Mauritii, Eisenia Andrei, Lampito Rubellus and Drawida Willis* [9]. However, Eisenia fetida (commonly known as 'Tiger Worm') is the most common species of earthworm to be utilized for vermicomposting [10-11]. E. fetida, is a eurythermal species, in that they can withstand an extensive temperature range, which makes them a popular choice for vermicomposting.

Figure 1.2: An adult earthworm - Eisenia fetida (Adopted from [12])

1.4 ***Biotransformation description:*** Composting and vermicomposting process: Composting is the biological degradation of organic waste, occurring in either aerobic [13] or anaerobic [14] environments, with the former being more prevalent. Organic waste is devoured as a substrate by aerobic thermophilic and mesophilic microbes, which then convert it to mineralized compounds such as CO_2, H_2O, NH_4^+ or stabilized organic matters [15]. The resulting compost is a complex, stable, humus-rich combination that can improve soil physical qualities [16]. Temperature, initial C/N ratio, aeration, porosity, moisture content, and pH are all factors that influence the composting process [17]. These factors are monitored and controlled during the composting process to provide an ideal environment for microorganisms to decompose organic waste [18]. Composting is a biological degradation of organic waste that results in vermicompost, a stabilized organic fertilizer. Vermicomposting uses interactions between earthworms and microorganisms to biodegrade organic waste more quickly, unlike composting [19]. By fragmenting and conditioning the substrate, earthworms are the primary drivers in the breakdown of organic waste. Earthworms do this by increasing the surface area of organic waste exposed to microbes. As a result, microbial activity and the decomposition of solid waste are improved. Vermicomposting produces vermicompost or earthworm cast with a low carbon-to nitrogen ratio, excellent porosity, water-holding capacity, and readily available nutrients [20]. The efficiency of the vermicomposting process is controlled by various elements, including the initial C/N ratio, moisture content, pH, and the composition of the organic waste, just like composting. In contrast to composting process, all parameters influencing vermicomposting are intrinsically tied to the earthworm species used in the biodegradation process.

1.5 Benefits of vermicomposting: Vermicompost, like conventional compost, provides many benefits to agricultural soil, including increased ability to retain moisture, better nutrientholding capacity, better soil structure, and higher levels of microbial activity. A search of the literature, however, indicates that vermicompost may be superior to conventional aerobic compost in a number of areas. These include: Availability of nutrients; Availability of beneficial micro-organisms; Enhances plant growth; Suppresses diseases; Repulses the pests; Reduces the use of fertilizer; Reduces the water requirement for irrigation; Increases the yield.

1.6 Vermicomposting Products

The process of vermicomposting produces earthworms as products by a process called vermiculture. Furthermore, vermicompost which is also termed vermicasts is produced together with vermiwash. The vermicompost and vermiwash can be utilized as bio-fertilizers [21].

1.6.1 ***Vermicompost*** (VC)***:*** Is becoming a popular form of compost in use today. It is produced through a process which utilizes vermitechnology, whereby earthworms are used to break down organic matter to produce compost. The process consists of these composting worms transforming organic matter into worm castings using their natural digestive function. This, in turn, leads to the production of vermicompost as the worm castings combine with some partially processed organic matter to produce this rich medium. [22] state that it is the earthworm species and the nature of raw material can modify the nutrient content and quality of VC, along with temperature and pH range.
The vermicompost obtained are also termed vermicasts as they are expelled as casts from the earthworm gut. Various types of organic waste have been reported to produce vermicompost and a range of nitrogen (N), phosphorous (P) and potassium (K).

1.6.2 ***Vermiwash:*** Is also known as '**vermitea**' is an organic fertilizer which is becoming popular with garden enthusiasts. Not much is known about it as it is a material which has only been used in recent years. [23] described vermitea as "a liquid fertilizer produced by passing water through columns of vermiculture beds". However, some confusion can arise in differentiating between worm cast and worm leachate.
As mentioned previously, 'cast' is a term used for the liquid extract from vermicompost, and is also known as 'vermiwash' or 'vermitea'. Vermiwash has been defined as "a leachate that is produced during the vermicomposting process and is dark brown in colour" [24].

1.7 Theory of Microorganisms Growth Kinetics:

Research scientist have used the existing inhibitory growth models and bio-kinetic parameters to model microorganisms' growth kinetics, when using microbes, which can transform chemical energy in an organic compound into electricity. This process by large provide an alternative route of renewable energy generation.

This research looked into the feasibility of employing composting and vermicomposting to bio-transform organic waste (fruit waste) bio-degraded in an MFC using microorganisms into an organic fertilizer as a long-term waste management approach and a sustainable solution in Smart Agriculture.

In conclusion, composting and vermicomposting may be the most promising solution for organic waste management, particularly in low income nations, because they are less expensive and have a more negligible environmental impact. Composting and vermicomposting processes produce organic fertilizer from trash, demonstrating that they fit the cleaner production paradigm. Furthermore, the global understanding of the need to recover valuable organic materials and return them to the soil is the driving force behind the development of composting and vermicomposting (or other reuse techniques) in organic solid waste management.

2. Materials and Methods

2.1 Sample collection: Fruit wastes and rumen fluid: Fruit and vegetable trash samples were gathered from rubbish piles in Nairobi city markets at random intervals. The wastes were separated and stored at room temperature in a laboratory for three days to allow natural decomposition. The scraps were then mixed separately and kept refrigerated until they were ready to use. Rumen fluid samples were collected from the Huruma slaughterhouse in 5-liter cooler box containers and transported to the Microbiology laboratory for bacteriological studies at the University of Nairobi's College of Agriculture and Veterinary Sciences.

2.2 Experimental procedure Composting: Market fruit wastes such as mango, banana, tomato, watermelon, and avocado were chopped and homogenized individually in a blender, then 100 g of each sample was placed in separate anodic chambers of the Microbial Fuel Cell. A 100 g mixture of all fruits samples was homogenized in a blender and supplied into a separate clean anodic chamber. 250 mL rumen fluid from the Huruma slaughterhouse was placed into the anodic cell to introduce the bacteria, while 500 mL distilled water was introduced into the cathodic cell. The current and voltage were measured every day for 30 days using a digital multi-meter. Following that, the MFCs' biodegraded waste was prepared for additional 45 days of Vermicomposting. Pathogen reduction and sanitization of organic waste are similarly dependent on the high temperature obtained in this phase.

2.3 Construction of the microbial fuel cell: The anodic and cathodic chambers were prepared in two 2-liter containers. A copper wire was passed through small holes punched into the lid of the two containers. One end of the copper wire was attached to a 5.7 cm long graphite rod electrode with a 0.7 cm diameter. Two and a half liters of 1M NaCl solution, 3% agarose powder, and lamp wicks were used to fabricate a salt bridge. The wicks were boiled in a mixture of NaCl and 3 % agarose solution for 15 minutes before being frozen at -4 °C to solidify. The solidified fabricated salt bridge was passed through PVC pipes and sealed with Araldite adhesive between the two chambers, making it leak-proof [25].

A multi-meter was connected to two copper wires from both the cathode and anode electrodes, and the current, voltage, and power were all measured 24 hours a day. The power output of a microbial fuel cell was determined and calculated as follows:

Ohm's Law: $V = I.R.$ (i)

Power Law: $P = VI.$ (ii)

Voltage (V) readings were obtained from a digital multi-meter as in (**Fig. 2.1)** below. The current output was calculated from the equation of Ohm's Law. The resulting power obtained was calculated based on the results of Voltage (V) as well as current (I) recorded, mainly when using power Law (equation ii).

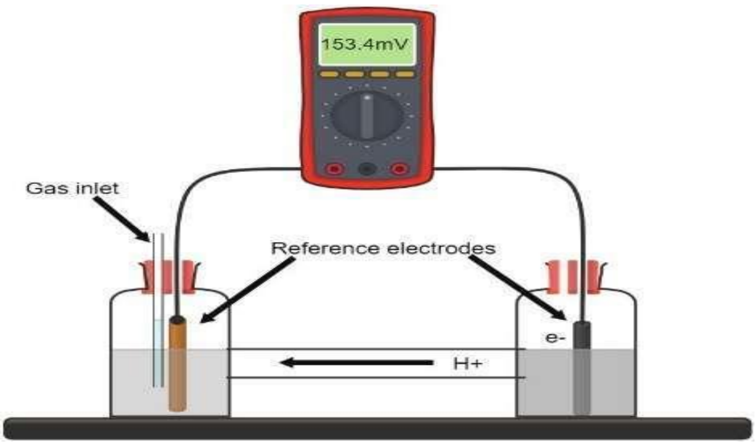

Fig 2.1: Set-up of Microbial Fuel Cell

In the anodic chamber, the substrate is broken down and converted into acetate. Electrons and protons are produced and transferred to the cathode chamber where they are consumed and then combine with Oxygen to form water. Below is the reaction taking place in the chambers.

$$\textbf{ANODE}: \ CH_3COO^-_{(aq)} + 2H_2O_{(l)} \longrightarrow 2CO_{2(g)} + 7H^+_{(aq)} + 8e^- \qquad (i)$$

$$\textbf{CATHODE}: \ 2O_{2\,(g)} + 8H^+_{(aq)} + 8e^- \longrightarrow 4\,H_2O \qquad (ii)$$

$$\boldsymbol{OVERALL}: CH_3COO^-_{(aq)} + 2O_{2(g)} + H^+_{(aq)} \longrightarrow 2CO_{2(g)} + 2H_2O_{(l)}$$

2.4 Preparation of Substrate from Fruit Waste: Microbial Fuel Cells were set up by using fruit wastes from mango, banana, watermelon, tomato, avocado, and a mixture of fruit waste as substrate. The fruit wastes consist of the peels and leftovers fruit content that were chopped into small pieces. The weighted fruit wastes were then mixed into a sludge that was used to set up MFCs. The weight of the fruit peels and fruit contents were fixed at 50 mL, totaling up to 100 mL of fruit waste per fruit type. The experiment was carried out and the voltage and power output of the MFCs were measured for 528 hours.

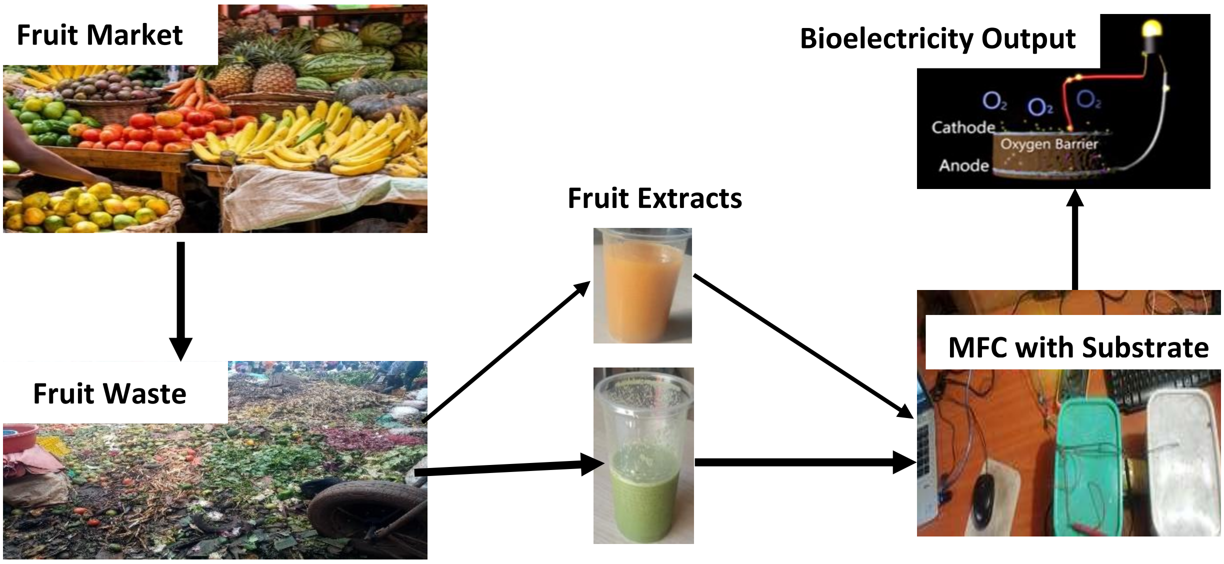

Fig. **2.2** Schematization of Bioelectricity generation process from fruit waste.

3. Results and Discussion

3.1 Voltage Generated by Fruit-waste

The data obtained is shown in **Fig. 3.1**. The average output was: 176.78 ± 95.17 mV in avocado, 215.97 ± 88.28 mV in banana, 187.57 ± 98.54 mV in mango, 186.39 ± 72.99 mV in watermelon, 145.76 ± 68.73 mV in tomato, and 158.77 ± 50.95 mV in mixture sample. The study showed that over the 22 days period, the voltage kept increasing, which is attributed to the activation loss or over-voltage. Because no external resistance was applied, the voltage data collected from the MFC was regarded as the open-circuit voltage. Moreover, high carbohydrate content levels resulted in high voltages, as evidenced in voltage output recorded on the 17^{th} day. The mixture of the various fruit-wastes produced significantly less voltage than individual fruit waste. This could be due to antagonism in competing for reactive activities inside an assortment of the waste, which hampered voltage production [26]. [27] observed an activation loss to be a portion of the available energy lost while driving transfer of generated electrons to and from electrodes. For example, anode's hydrogen oxidation reaction may be swifted, while the cathode's oxygen reduction reaction is slow [28], and therefore, the voltage drop would be dominated by the cathode reactions. **Eq. 3.1** of the Tafel formula describes relationship between activation over-potential and current density [26].

$$V_{act} = a\ln\left(\frac{i}{i_o}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where; a - (Tafel slope) and io(A/m^2), (exchange current density) are coefficient constants that can be estimated empirically. The current density, i (A/m^2), is the ratio of fuel cell current, if C(A), over active cell area expressed in cm^2). However, Tafel equation 3.1 is only valid for i > (i_o). The typical value of (i_o)is about 0.1 mA/cm^2) [26]. This would explain why as the generated voltage increases, current decreases in microbial fuel cells. We found that market fruit waste was degraded with an efficiency range of (21.11 % - 35.95 %) for the first ten days and a range of (44.40 % - 88.75 %) for the following seven days, notably by anaerobic process. The bacterial degradation rate raised from initial percentage average of 31.58 % in between 1st to 10th day to an average percentage of 60.70 %, an upward increase of 52.03 % degradation rate. These findings justify the influence of specific bacterial growth curve phases and their degradation rate.

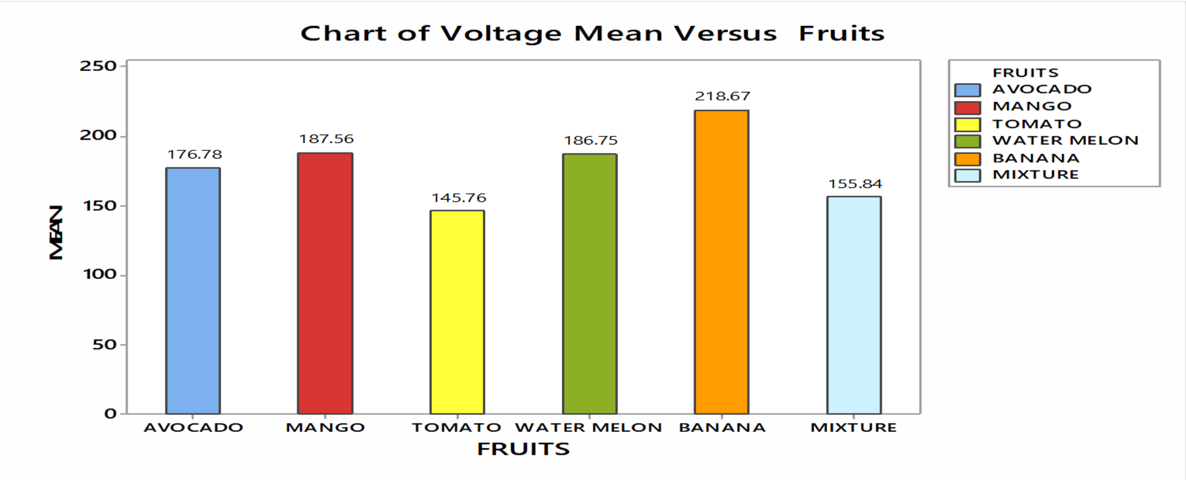

Figure 3.1: Voltage generated from the different fruit wastes during the experimental period

The amount of energy required to break down avocados' high fat content explains a low voltage output observed in **Fig. 3.1** despite the relatively high carbohydrate content. [29]

observed that, in an open-circuit, organic waste generated voltage of 179.7 mV after 40 minutes. The voltage kept rising proportional to time for all fruit waste examined. A similar survey by [30] indicated that when using 500 g of organic waste as substrate in an open- circuit MFC, a potential of 0.27 V was generated which kept increasing for 5 days after which it started declining; suggesting that there were enough nutrients in the substrate to generate the voltage observed.

3.2 Current generated by Different Market Fruit-wastes

Current generated in an open circuit by goat rumen fluid using a double chamber MFC was recorded each day for 22 days (**Fig. 3.2**). The current generated increased from day one to day nine, then decreased after day nine, according to the findings. The maximum average current was generated on day 9 which was 0.033 mA in tomatoes, while the minimum average of current was 0.027 mA in banana fruit.

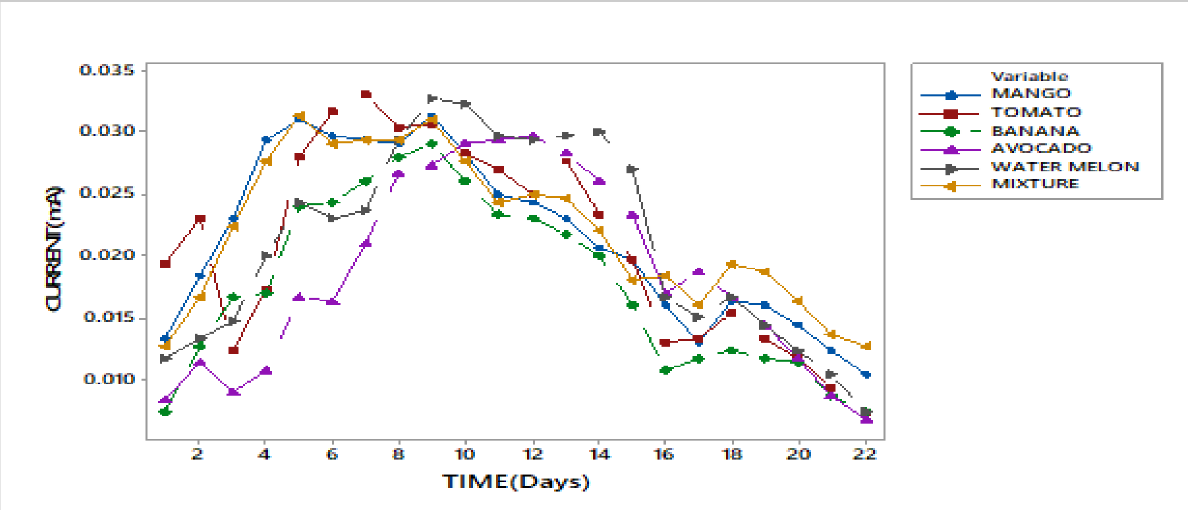

Figure 3.2: Generated Current from different fruit waste from day 1-22

[31], observed, proximate values of the wet fruit wastes, the tomato sample recorded a high moisture content (95.3 ± 4.0 %) followed by watermelon (92.85 ± 4.55 %) and lowest in the banana sample (74.3 ± 2.1 %). The flow of current is triggered by the flow of electrons across conductors. The rate constant of reactions in the liquid phase is inversely proportional to the viscosity of the solvent [32]. When the viscosity is low (the moisture content is high) we expect that the electrons would move faster across the system, thus a higher current is generated [33]. In contrast, when viscosity is low, we expect electrons would move slower across the system, and the current generation is therefore low. Tomato fruit-waste peak was at 0.033 mA; banana peaked at 0.029 mA and avocado at 0.027 mA. [34] and [31] observed

that, in Microbial Fuel Cells, high moisture content facilitated the creation of increased electron mobility in the solution which enhanced the flow of electrons in the cathodes.

3.3 Generated power from the market fruit-waste

Power generated by goat rumen fluid using double chamber MFC was recorded daily for 22 days for various fruit wastes (**Fig. 3.3**). Maximum generated average power was 4.4 µW on day nine in the banana fruit, while the lowest generated average power was 2.51 µW in mixture of fruit waste on the 9th day using **Eqn. 3.2**. The power data recorded was from an open-circuit source, having no load applied on it.

$$P = VI \tag{3.2}$$

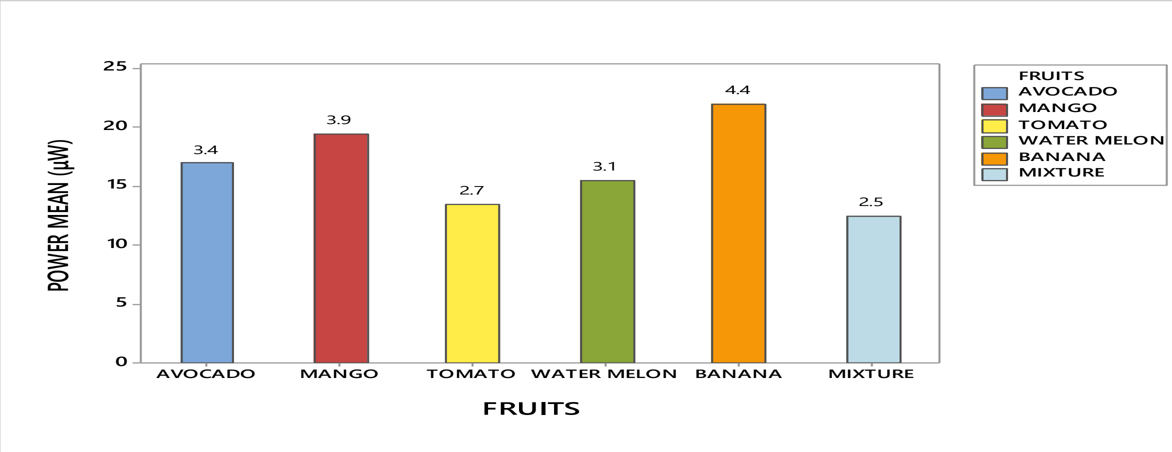

Figure 3.3: Average Generated power values from the different fruit waste

It is observed in **Fig. 3.3** that the highest power output was recorded for banana 4.4 µW and the lowest power output in mixture of waste at 2.5 µW while avocado recorded an output of 3.4 µW, 3.1 µW for watermelon, 3.9 µW for mango, and 2.7 µW for tomato fruit wastes respectively. [35] reported that the efficiency of MFCs is measured in relation to generated power and coulombic efficiency. [36] observed that power generated from market fruit wastes ranged between a power output of 0.081 µW to 12.06 µW for watermelon and 0.08 µW to 10.24 µW for fruits mixture, which was comparable to the power output in the present study.

3.4 Generated power density from the market fruit-waste

The Power density (mW/m^2) generated from the various fruit wastes according to power density equation, (**Eqn. 3.3**). The mean output generated by the fruit wastes was highest in banana fruits waste at 0.826 ± 0.380 mW/m^2, 0.582 ± 0.196 mW/m^2 in watermelon, 0.507 ± 0.190 mW/m^2 in tomato, 0.733 ± 0.290 mW/m^2 in mango, 0.639 ± 0.250 mW/m^2 in avocado and a mixture recorded output of 0.469 ± 0.164 mW/m^2.

The average power density outputs for 22 days from various market fruit-wastes are presented in **Fig. 3.4**. The results indicated that the mango sample gave the highest output. Each fruit's acidity level was measured, with mango fruit having the highest values, followed by tomato and watermelon, and banana recording the lowest amounts. Acidic fruits contain citric acid that could break up into charged anions and cations. These ions can conduct electricity as the charged particles can flow within the acid [37].

$$\text{Power Density} = \frac{\text{Power}}{\text{TSA}} \tag{3.3}$$

Where: (V) denotes voltage, (I) denotes current, and (TSA) denotes Total Surface Area.

$$\text{S.A} = 2\pi r^2 + 2\pi rh = 2\pi r\,(h + r).$$
$$\text{Give: Diameter} = 0.7\text{cm}, \text{Height} = 5.7\text{cm}, \text{Radius} = 0.35\text{cm}$$

$$\text{TSA} = [2 * 3.143 * 0.35\text{cm}\,(5.7\text{cm} + 0.35\text{cm})]$$

$$\text{TSA} = 13.3106\ \text{cm}^2 \qquad \text{But: } 1\text{cm}^2 = 0.0001\text{m}^2$$

$$\text{TSA} = 0.001331\text{m}^2 \qquad \text{But since we used four (4) pieces of electrodes}$$

$$\text{TSA} = (0.001331\text{m}^2 * 4) = 0.005324\ \text{m}^2$$

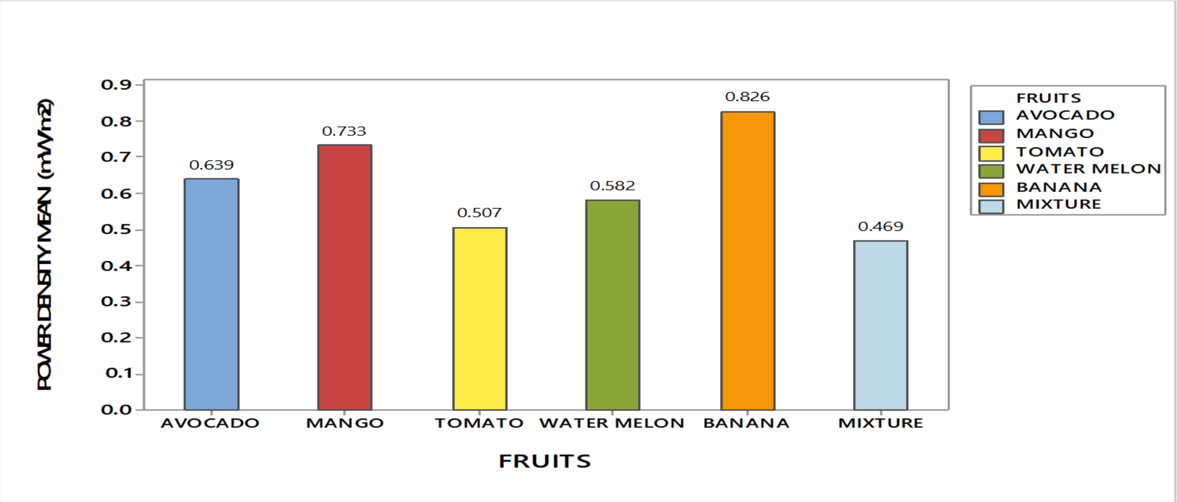

Figure 3.4: Generated average power density from different fruit waste

[38], observed power-density output of 340 µ W/m^2 recorded when using cow dung (substrate), while [39] recorded a power density output of 8.15 W/m^2. [40], using cow dung as substrate (fed on anodic portion), produced a maximum power density of 0.947 µ W/m^2 on day five, while on day 1, a minimum power density generated was 0.269 µ W/m^2. This study showed that from day 1 to 6, the maximum generated potential, current, power, as well as the power densities results showed comparable characteristics. A considerable population

of microorganisms existed before and after the period of electric energy generation, according to measurements of the microbial load; their presence implies and establishes their role in aiding the release of protons and electrons, which results in the generation of electricity as a whole. As a result of the MFC chambers' microbial activities, power density output was continually produced during the experiment with a subsequent decline in production that was attributed to the exterminated organisms. The upward and downward trend followed a similar pattern as is reported by [41]. On day 5, all of the fruit waste output measurements were found to be at their highest levels as compared to the first experiment day, which could be attributed to high substrate impedance caused by incorrect substrate and water mixing, as well as the microbes were still in the lag phase [42].

3.5 Vermitechnology Experiment On-Site

3.5.1 Economic Value Addition on the Biodegraded Fruit Waste

As current waste treatment methods are becoming unsustainable, alternative techniques are being pursued. One such method is the use of **Vermitechnology** as a safe, sustainable approach for treating organic waste that is becoming increasingly popular as a management strategy for organic waste [9]. Vermitechnology can be defined as the process which combines the techniques of both vermicomposting and of vermiculture.

The bio-amendment agent (bio-fertilizer) on homemade vermicompost chamber production was set up on biodegraded market fruit waste. The biosludge that remained in the anodic chamber of Microbial Fuel Cell after the 22 days that current and voltage were monitored, was put in a locally made vermicompost chamber for further 45 days, a process that was regarded as vermicomposting, after which it was investigated for bio- fertilizer.

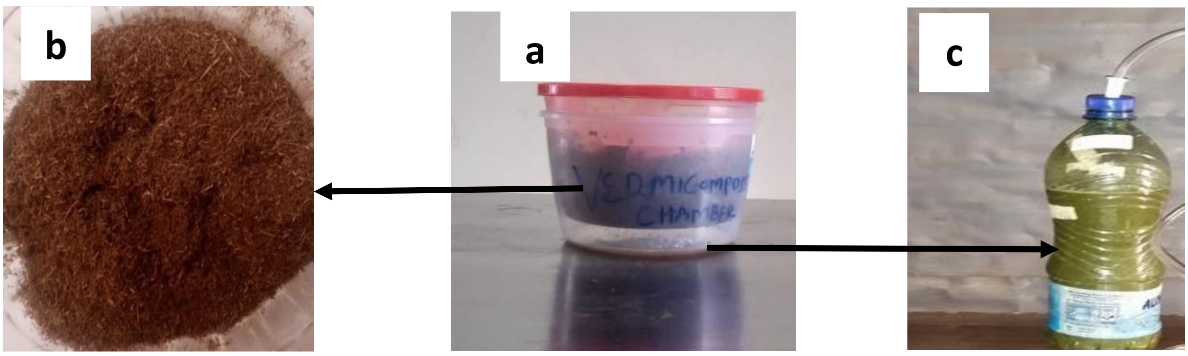

Figure 3.5: (a) Shows Homemade vermicomposter chamber, (b) Powder Vermicast, (c) Vermiwash

Shimadzu's IRAfinity-1S Fourier-Transform-Infrared Spectrophotometer utilized to analyze functional-groups in composite as well as in vermicompost sample. FT-IR technique works by creating an evanescent wave by utilizing the total internal reflection feature. Spectral resolution was set at a wavenumber 4 cm^{-1} while scanning range was from 400 cm^{-1} to 4000 cm^{-1} [43].

The initial and final Fourier-transform infrared spectroscopy spectra of utilized substrates are shown]below in **Fig. 3.6**, where it is observed that, most intense peak at 3400 cm^{-1} belong to O-H stretching bond, while peak at 1000 cm^{-1}, 1625 cm^{-1}, 2750 cm^{-1}, 2875 cm^{-1}, 3375 cm^{-1}, 1625 cm^{-1} belongs to alkane (C-H) bending, alkene (C=C) stretching, carbonyl (C=O) stretching, (H-C=O) stretching bonds.

FT-IR spectrum with background correction

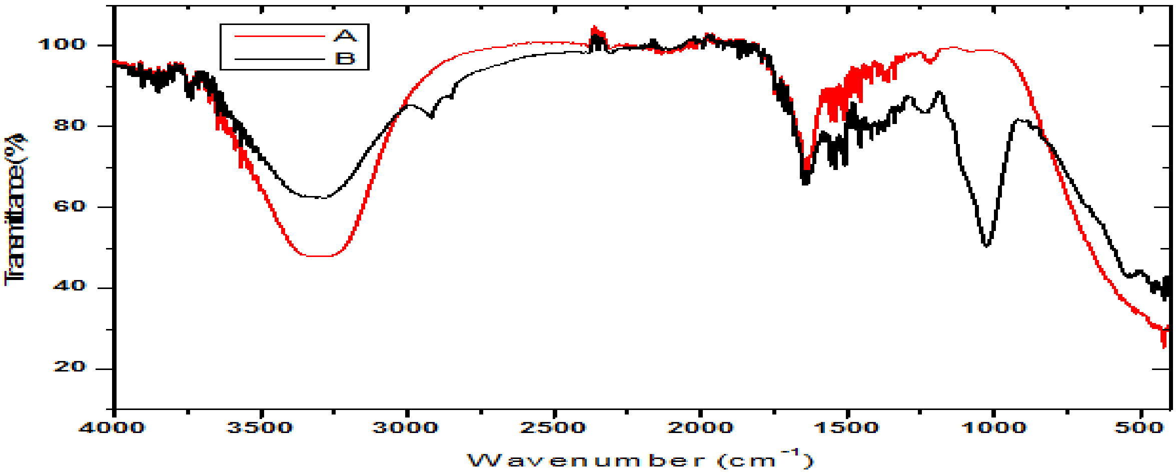

Figure 3.6: FT-IR spectrums of composite and vermicomposite

Above spectra demonstrates functional groupings in two spectrums using an FT-IR-ATR technique. The peak at spectra-A is related to Acetic acid of molecular weight 60.05 g/mol, indicates a rise in the amount of the active group coupled with molecular bond (per unit volume). Spectra-B was connected to butyric acid, which has a molecular weight of 88.11 g/mol. In a similar study by [44] bands that appeared at peaks 3407.6 cm^{-1}, 3435.5 cm^{-1} and 1545.0 cm^{-1} were attributed (N-H) stretching and (C=O) stretching bond vibrations, respectively.

As can be clearly seen on the FT-IR spectrum, that intensity of transmittance peaks decreased compared to initial spectrum, which according to [45] attributed this to degradation of microorganisms in the process of bioelectricity generation and vermicomposting procedure on the biosludge from the microbial fuel cell [46]. The Composite (Bio-sludge) and Vermicast (organic fertilizer) were examined for chemical composition, macro and micro nutrients and the results are tabulated in the Table 3.1 and 3.2 below.

Table 3.1: Properties of the Composite product

Chemical properties of the Composite

PH	8.83 ± 0.05
EC	0.814 dS/m
(g/kg) OM	179.2 ± 1.0
C/N Ratio	7.1 ± 0.2
Macronutrients of the Composite (g/kg)	
Mg	1.3 ± 0.02
N	32.4 ± 1.4
P	8.9 ± 0.1
K	0.003 ± 0.00004
Ca	1.8 ± 0.22
Micronutrients of the Composite (g/kg)	
Mn	ND
Fe	4.85 ± 0.08
Cu	0.17 ± 0.01
Zn	ND

Table 3.2: Properties of the Vermicast and Vermiwash product

Chemical properties of Vermicast/Vermiwash	
PH	9.84 ± 0.05
EC	0.552 dS/m
(g/kg) OM	335.2 ± 1.8
C/N Ratio	6.43 ± 0.2
Macronutrients of Vermicast (g/kg)	
Mg	7.1 ± 0.11
N	87.0 ± 3.8
P	7.6 ± 0.07
K	18.0 ± 0.23
Ca	97.4 ± 11.9
Micronutrients of Vermicast (g/kg)	
Mn	16.74 ± 0.022
Fe	6.61 ± 0.11
Cu	0.62 ± 0.03
Zn	0.013 ± 0.0001

According to vermicast evaluation result, (Table 3.2), chemical properties tabulated are satisfactory for crops' growth, soil fertility suitable for farming and organic matter is sufficient, having a total organic carbon (TOC) of 384.1 g/Kg up from 20.825 g/Kg initially in a biodegraded organic waste [47]. This is because vermicomposting has the higher decomposition rate and nutrient content of the final product [48]. In addition, vermicomposting produces a higher concentration of hormones and enzymes that could stimulate plant growth, enhance soil fertility, reduce pH, provides micro and macronutrients, and increase their availability as well as help soil to absorb and retain water [49]. The organic matter in fruit waste sample is converted to a dark sludge via an anaerobic digestion process in 30 days, before being bio-amended into a better-quality organic fertilizer by bulking agents (epigeic varieties of earthworms) [47]. As a result, enhanced vermicompost may be concluded to promote better plant growth while also improving soil health and fertility. It is suggested that enhanced vermicompost be researched for its application in agriculture for improvement of crop yield.

3.6 Investigation on the use of vermicast and vermitea as a plant growth promoter

In recent years, sustainability in agriculture has become important due to issues such as soil degradation and pollution [50]. Synthetic fertilizers are one of the most popular means of promoting plant growth through the addition of ‘man-made’ agrochemicals to provide important nutrients such as nitrogen (N), potassium (K), phosphorus (P) and other microelements that plants need for growth and development.

Fertilization is one of the main costs of crop production in Kenya and worldwide. There are two types used: straight fertilizers (containing only one element, e.g. potash) and compound fertilizers, containing more than one element, e.g. N, P and K.

An example of a leading commercial horticultural compound fertilizer is MEA Fertilizer (from now on referred to as MF), which is available in both granular and liquid forms. For this study a formulation of NPK (0: 23: 15 + 10CaO + 4S). Due to the high cost of fertilizers rand their environmental impact, their use is becoming more unsustainable, which is why it is necessary to research for alternative soil fertility enhancers, through organic systems, such as vermitechnology, reducing the cost of crop production and limiting the environmental effects, while retaining the nutritional benefits to ensure cost-effective production of these crops in the future. Vermitea (or ‘vermiwash’) is a form of leachate of vermicompost that contains minerals and vitamins which can enhance plant growth and improve growth performance [51] and therefore is used as a biological fertilizer [50].

3.6.1 The effect of vermitea against a commercial fertilizer on Agricultural crops

The vermicast (organic fertilizer) and vermitea or vermiwash produced from composite were then applied on a maize and beans plantation and the growth process of the plants monitored. This was compared with the application of synthetic compound fertilizer on the plants as animal manure was used as the control. The results were obtained and are shown below.

Figure 3.3. Early seedling development trials (Maize)

3.6.2 Statistical analysis

A (x^2) test of homogeneity (IBM SPSS, Version 23, 2015) was conducted in all seed germination trials to determine which treatments affected the respective germination rates of all crops studied. Each of the three groups representing a treatment applied in the experiment as outlined in (**Table 3.3 – 3.5).**

A Kruskal, Wallis test (1952; IBM SPSS, Version 23, 2015) was conducted to evaluate if any statistically significant differences were present among all treatments applied in terms of root and shoot height of all crops studied. If the null hypothesis was rejected ($p < 0.05$), subsequently, pairwise comparisons were performed using Dunn's (1964) procedure and a Bonferroni correction for multiple comparisons.

3.6.2.1 Effect on seed germination

With respect to germination of maize seeds, the control treatment was the best treatment, in that neither of the other fertilizer treatments aided in germination sufficiently. In beans, 100% VT affected germination significantly, as seen in Table 3.3. Commodity inorganic fertilizers (MF) treatments resulted in low percentage germination of seeds.

Table 3.3: Germination percentage of maize and beans observed under various fertilizer treatments

	Maize	**Beans**
Manure (control)	34% ***	44% ***
100% MF	3%	21%
100% VT	23%	64%

*** $p < 0.001$

3.6.2.2 Root and shoot growth in seed germination

For maize and beans in this experiment, 100 % MF had a significant adverse effect on both root and shoot height, $p < 0.001$. For maize, both for root length and shoot heights, no treatment produced better results than the control, as seen in Table 3.4. Therefore, in this instance, manure is seen to be the best treatment for maize due to high nutrient content as well as high composting matter. VT 100 % produced similar results to the control for root length of beans, while it resulted in better shoot height for beans (Table 3.4)

Table 3.4. Root length and shoot height (cm) (± SD) of maize and beans crop seedlings under various fertilizer treatments

	Root Length	
Treatment	Maize	Beans
Manure(control)	1.5 ± 1.8	2.2 ± 1.7
100% MF	0.9 ± 0.1	0.5 ± 0.1
100% VT	1.3 ± 1.8	2.3 ± 1.4
	Shoot Height	
Manure(control)	0.7 ± 1.1	1.1 ± 1.2
100% MF	0.4 ± 0.1	0.1 ± 0.2
100% VT	0.6 ± 1.1	1.4 ± 1.0

*** $p < 0.001$

Better results on plant leaf appearance and health were observed to be better in the set with the vermicast or vermitea (VT) followed by the set with dried manure (control). In the blank set, the crops started dying due to the depletion of nutrients in the soil.

3.6.2.3 Effect on early seed development

There were no statistical differences present among all treatments for root length of maize and beans ($p > 0.05$). With respect to maize, 100 % VT produced the greatest root length compared to the control, with 100 % MF for shoot height (Table 3.5). Both VT treatments produced the greatest root growth for oat. While the control treatment had a significant effect on the shoot height of oat, 100 % VT produced slightly better shoot height (Table 3.5).

Table 3.5: Root and shoot height (± SD) of spring barley and oat seedlings

	Root Length	
Treatment	Maize	Beans
Manure (control)	14.0 ± 5.0	11.4 ± 3.5
100% MF	14.1 ± 4.0	15.1 ± 3.6
100% VT	15.5 ± 5.0	15.8 ± 3.3
	Shoot Height	
Manure (control)	40.3 ± 7.0	21.2 ± 2.9***
100% MF	41.7 ± 5.6	21.2 ± 3.3
100% VT	41.2 ± 8.2	21.6 ± 3.6

*** $p < 0.001$

This section focused on the application of vermicast and vermitea on two agricultural crops. Experiments were developed to compare vermitea to a commercial chemical fertilizer (MF) with a control treatment of manure to represent no fertilizer addition. Both seed germination along with root and shoot growth was measured to determine if vermicast or vermitea (an organic solution) could produce similar plant development results to those generated by a leading chemical fertilizer. While fertilizer use in Kenya is still dominated by commodity NPKs, new emerging products are designed to meet balanced crop-specific nutrient demands, based on perceived nutrient deficiencies. It is not clear that all of the nutrients in these formulations are required, but they are attractive for use by farmers compared to commodity fertilizer especially as growth promoters.

The main findings were:

i. Earthworms reduce food waste quicker than that of a plain composting system.
ii. Smaller amounts of VC (1g and 5g especially) can be soaked over 1- 45 days to produce vermitea which has good amounts of orthophosphate and potassium, along with notable levels of pH, electrical conductivity, salinity and total dissolved solids. The results showed that the VC weight and not the soakage time length was a significant factor.
iii. Vermitea from the in-house vermitechnology system had significantly different physico-chemical and nutrient parameters in comparison to liquid samples from the control, which was a normal composting system without earthworms.
iv. Beans benefits hugely from VT treatment; however further testing could be conducted to examine this in more detail.

Previous work has been done by other researchers on the use of vermicompost for plant development [51-52], however less on the use of vermitea. In this study, the use of composite in Smart Agriculture experiment compared both chemical and vermitea treatments on seed germination of maize and beans.

[22] noted other important properties of Vermicompost (VC) including:

- Significant levels of bioavailable nutrients for plant and beneficial soil microorganisms.
- A state free from the presence of pathogens and harmful chemicals.
- Its ability to repel plant pests and aid in the suppression of plant diseases.

The aim of this experiment was to explore the potential of vermitechnology as a possible alternative waste management solution for sustainable smart agriculture practice. It also aimed to analyze the physico-chemical and nutritional properties of VT, sourced from both an on-site system and from a preparation of commercially acquired VC. Finally, VT was compared to a compound chemical fertilizer, as treatments to various species of plants to investigate the possible role of VT as a plant growth promoter.

4. Conclusion

Bioconversion of solid waste by the use of earthworm into nutrition rich vermicompost can become an economical process for the farmers and local environment cleanup bodies, saving substantial amount of money and environmental security affected by deposition of solid waste in environment. When the yield, height, number of leaves and roots as well as the biochemical composition of the leaves of maize and beans grown using vermiwash and vermicast, it was noted that the yield was slightly higher than that of the commercial fertilizer, a factor that means that the vermicompost can be used in place of the commercial fertilizer. The vermicompost, generally, has a greater advantage over commercial fertilizer as it is highly degradable and results to organic and, therefore, healthier crops.

This work has highlighted how useful the used technologies can be in reducing food waste which is currently sent to landfill, while producing bio-energy and a nutritional organic fertilizer, which could be used to aid in the germination of many crops, thus hopefully in the future in reducing the quantities of chemical fertilizers used in this country, especially in horticultural crops.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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