

ORIGINAL RESEARCH ARTICLE

Bioelectricity Generation from Onion Waste

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ABSTRACT

Due to the culinary and medicinal importance of onions, they are widely consumed as a vegetable. Electrogenic microorganisms, commonly found in the environment, are characterised by their ability to generate electricity. Most of these microbes are bacteria and fungi. In this study, bioelectricity was produced from onion waste. The investigation involved isolating and identifying the microorganisms present in the onion waste sample. Additionally, the nutritional content and pH level of the onion waste were analysed. Bioelectricity was generated over 16 days in a microbial fuel cell (MFC) with a copper anode and a zinc cathode. Composting and mixing the samples produced a slurry of onion waste. Microbiological analysis revealed the presence of twelve bacterial species, including *Bacillus subtilis*, *Proteus mirabilis*, *Micrococcus spp.*, and *Staphylococcus aureus*, as well as six fungal species: *Alternaria alternata*, *Aspergillus niger*, *Penicillium digitatum*, and *Saccharomyces cerevisiae*. The results indicated a high moisture content at the initial stage (90.5%), which is consistent with its nutritional makeup. The pH ranged from 3.0 to 4.3, indicating an acidic environment. The highest voltage, 429 mV, was recorded on the first day, while the maximum current and power density, 2.1 mA and 11 mW/cm², were observed on the fourth day. These findings suggest that discarded onions could be used to generate power for various applications. Further research is needed to assess the total power output and the duration of the process. Monitoring the continuous production and harvesting of rapidly growing electrogenic microbes could enhance both performance and efficiency.

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INTRODUCTION

In addition to its culinary, garnishing, and medicinal use, the onion, scientifically known as *Allium cepa* L., is a widely produced vegetable utilized worldwide (Mike and Martin, 2009; Ravi, 2016). As one of the most important vegetables grown in Sokoto State, it plays a significant role in both Nigeria's exports and consumption. Despite the production being confronted with several difficulties, such as storage and post-harvest damages, which result in a reduction in its yield (Kaka et al., 2022).

The vast majority of the damaged items end up as waste resources that are seldom used, becoming contaminants of the environment. The effective utilization of waste for the generation of renewable energy, such as biofuel and bioelectricity, will play a crucial role in the near future (Matemilola and Elegbede, 2017; Kaka et al., 2022; Segundo et al., 2022). The generation of bioelectricity from onion waste, an organic source, is a novel approach that will aid in waste management (Haruna et al., 2023). This may be accomplished through the use of microbial fuel cells (MFCs), a method that generates power favourably for the environment (Nwaokocha et al., 2021).

The MFC is a chamber or biochemical device in which microbial activity, such as ion exchange from the electrolyte produced as a result of enzymatic activities and metabolism, is transferred to the electrodes connected to the cell, leading to the generation of bioelectricity (Flores-Treviño et al., 2019; Hindatu et al., 2017). The presence of microorganisms enables metabolic and enzymatic processes to occur in the chamber. It is possible to generate electricity through the activity and metabolism of microorganisms. This is possible because of the ionic charges and exchange that occur inside the electrolyte formed from the onion's waste (Flores-Treviño et al., 2019). The use of waste resources will compromise cost-effectiveness and food security. This contrasts with the use of food resources as a biomass source for renewable energy. As a result, materials that are considered garbage can serve as an excellent alternative energy source (Rabe et al., 2017).

Although fossil fuels (coal, natural gas, and petroleum) are formed from decomposed animal and plant matter that has been there for millions of years, they are not

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renewable. Therefore, they provide high-efficiency electricity used to power automobiles and electronic gadgets, which is an unsustainable source of energy. This led to the search for an alternative method for utilizing biomass to generate power and energy that is both sustainable and environmentally friendly (Rabe *et al.*, 2017).

Due to its ability to generate energy from various organic sources, biomass is a clean energy source that does not contribute to pollution. It has the potential to serve as a replacement for fossil fuels at the same time. Higher power may be achieved by utilizing appropriate biomass and microorganisms, which would assist in addressing global warming, providing environmentally friendly energy, achieving cost-effectiveness, and attaining Sustainable Development Goals in terms of food security and climate change initiatives.

One of the several states in Nigeria that produces a significant number of onions is Sokoto State. There are difficulties that arise after harvesting onions, which are grown virtually continuously throughout the year (Kaka *et al.*, 2022). It is estimated that the majority of this onion waste is either consumed or disposed of in the environment or on farms, resulting in environmental contamination, pollution, and health problems (FAO, 2015). Due to the degradation of post-harvest waste and the provision of energy, the sustainable utilization of this waste will play a significant role in addressing ecological issues; it will also help limit the release of gases into the environment, which, in turn, will contribute to lowering the rate of global warming. Furthermore, the issue of electricity supply is a significant concern that has a substantial impact on people's lives and the nation's growth in Nigeria (Haruna *et al.*, 2023).

Waste management is one of the most significant environmental issues faced worldwide. Instead of relying on food sources to generate energy (Kumar *et al.*, 2022), utilizing waste in energy production through renewable energy sources is a key turning point that can aid in addressing the problem of food security (Szulc *et al.*, 2021; Logroño *et al.*, 2015). This can be accomplished by utilizing power from renewable energy sources (Aderoju *et al.*, 2017; Kaza, *et al.*, 2018 Salisu *et al.*, 2023). Despite this, plant biomass produced a small amount of electrical charge; the addition of electrogenic microorganisms associated with onion rotting and other metal sources will result in the generation of bioelectricity (Rojas-Flores *et al.*, 2021).

Though. Research was conducted on the utilization of wastewater, rotten vegetables and fruits, such as pineapple, potato waste, and kitchen (Haruna *et al.*, 2023; Hindatu *et al.*, 2017). However, little or no research has been conducted on onion waste in the study area, which is one of the major onion-producing states in the country and faces post-harvest challenges. In order to generate bioelectricity from onion waste, the research aims to isolate and identify electrogenic microbes. The objectives of the research are as follows: (i) to isolate and identify the electrogenic microorganisms that are present in the onion

waste anodic chamber; (ii) to conduct a biochemical assessment of the onion slurry; and (iii) to evaluate the electrical properties of the electrogenic microbes and the onion slurry.

MATERIALS AND METHODS

The overview of the method is presented in Figure 1.

Collection and Preparation of Onion Waste

Samples of decomposed onions weighing 100 kilograms were collected from agricultural markets and processing sites in Sokoto. Afterwards, the samples were taken to the laboratory for sorting, proper identification, and preparation for the experiment.

Pre-treatments and slurry preparation

It was necessary to remove debris, impurities, and undesirable material from the onion sample. Additionally, distilled water was used to wash away dust and contaminants, as described by Flores-Treviño *et al.* (2019) and Hindatu *et al.* (2017). Depending on the type of decomposed onion sample taken. The sample was placed in a large container for a period of time to provide suitable conditions for decomposition. To produce approximately 1,000 milliliters of slurry, the waste was liquefied using a blending method for 20 minutes.

Morphological Isolation and Identification of Post-harvest Microbes

To isolate and morphologically identify the microorganisms (bacteria and fungi) responsible for onion degeneration, *in vitro* culture and subculturing were performed in suitable media to obtain pure cultures of each microbial isolate. The morphological characterization was carried out with the help of a microscope and an atlas, as follows:

Preparation of Culture Media



Plate 1: Prepared media for fungal isolation

Various types of media were used (Plate 1), including Nutrient Agar (NA), MacConkey Agar (MA), Eosin Methylene Blue Agar (EMBA), Blood Agar (BA), and Salmonella-Shigella Agar (SSA) for bacterial isolation, while Potato Dextrose Agar (PDA), Malt Extracts (ME),

and Sabouraud Dextrose Agar (SDA) were used for the fungal identification. All the media were prepared according to the manufacturer's instructions.

Isolation of Bacteria

The pour-plate method (Harigan and McCane, 1990) was used for isolation. A tenfold dilution of the sample was prepared by adding an aliquot to 9.0 milliliters of sterile water. The sample weighed 1.0 gram. This was achieved using the standard microbiological method called serial dilution. The sample was then mixed with nine and a half milliliters of sterile, distilled water. One milliliter of the aliquot (supernatant) was pipetted into a test tube, and the contents were thoroughly mixed. The dilution was expressed as a tenth, denoted by 10^{-10} :10. Afterwards, 1 mL of the fourth and seventh dilutions was transferred aseptically, and the next steps involved plating these dilutions in duplicate on sterile, molten nutritional agar.

Subculture of Bacterial Isolates

Using a sterile wire loop, colonies were selected from plates cultured for 24 hours for aseptic procedures. Then, a streaking method was employed to transfer these colonies onto a newly prepared sterile nutrient agar plate. After incubation, different colonies appeared at the ends of the streak lines. Over 24 hours, the culture plates were incubated at 37 degrees Celsius. Once the colonies were removed from the culture plates, they were transferred aseptically, streaked onto slants, and cultured for an additional 24 hours at 37 °C as described by Akinmusire (2011) and Danaski *et al.* (2022).

Characterization and Identification of Bacterial Isolates

Isolates were stained using the Gram staining technique, after which a microscopic examination was performed for morphological characterization. This examination focused on the dimensions, shape, color, consistency, pigmentation, and tactile characteristics of the colonies, as well as the unique groupings and cell arrangements present among them. In addition, biochemical tests, including the indole test, the methyl red test, the Voges-Proskauer (VP) test, the citrate test, the oxidase test, the germ tube test, and the sugar fermentation test, were carried out in order to more accurately identify the bacterial isolates, as follows:

Biochemical Tests

(a) Catalase Test

To achieve this, the approach outlined by Ban *et al.* (2021) was carried out systematically. One loop containing a fresh bacterial culture was placed on a microscope slide with two drops of a solution containing 3% hydrogen peroxide. The loop was then placed on the slide. The presence of bubbles allowed for the determination of whether the responses were positive for catalase.

(b) Oxidase Test

This entire series of examinations was conducted in a manner consistent with the process outlined by Schaad (1988). By dissolving 0.1 grams of N'-Tetra methyl-p-phenylene diamine dihydrochloride [$C_6H_4[N(CH_3)_2 \cdot 2HCl]$] in 10 milliliters of pure water, a solution with a concentration of 1% was created. The preparation of the remedy will be achievable as a result of this. A fresh culture of bacterial colonies was collected from the medium using a wooden stick. This culture was then combined with the solution produced on the Whatman filter paper layer. After thirty seconds, the isolates generated a hue that was either blue or a deep purple. The isolates formed this color. A positive result was recorded upon completion of the oxidase test.

(c) Tween 80 hydrolysis test

In a flask made from Erlenmeyer glassware, the following components were mixed: 15 grams of agar, 10 grams of peptone, 5 grams of sodium chloride, 0.1 grams of calcium chloride, and 2 grams of water. A further step involved heating the mixture to completely dissolve the components. When the media volume reached 10 milliliters (10 ml), Tween 80 was first placed in a separate container and autoclaved. After that, it was added to the medium. The spot inoculation technique was used to transfer a loopful of a new broth culture onto an agar medium. This was done after the loopful was obtained from fresh broth culture. A temperature of 30 °C was maintained during incubation, which lasted up to 7 days. The formation of an opaque zone of crystals encircling a colony was thought to result from a positive reaction during the hydrolysis of Tween 80, as described by Schneider *et al.* (2023).

(d) Starch Hydrolysis Test

As a result, 5 g of soluble starch at 2% concentration was added to the nutritional agar medium, melted, and then poured into sterile Petri dishes to solidify. This was done to ensure the accuracy of the results. The plate was then incubated at 30 °C until heavy growth occurred. A single streak inoculation of each bacterium was performed at the center of the plate using sterile technique. After that, the plate was incubated according to the method described by Schneider *et al.* (2023). For the duration of thirty seconds, an iodine solution was administered using a dropper. There were observations made about the colony.

Isolation of Fungi

The medium was prepared in accordance with the manufacturer's instructions. An aseptic procedure was used to produce Potato Dextrose Agar (PDA), Malt Extract (ME), and Sabouraud Dextrose Agar (SDA). After that, the prepared medium, which was approximately 15-20 milliliters in volume, was poured onto the plates and allowed to settle at room temperature (28 ± 2 degrees Celsius). After the onion waste slurry had been prepared, it was transferred aseptically to sterile petri plates containing different media. This was done in order to maintain the integrity of the laboratory. Over the

course of five days, the petri dishes were incubated at 37°C in an incubator and were kept under close observation on a regular basis (Tafinta *et al.*, 2013).

Subculture of Fungal Isolates

The colonies that had developed after five days were enumerated and selected using a sterile injection needle in an aseptic manner. After that, they were subcultured multiple times on PDA, SDA, and ME, and then incubated for five days at 37 degrees Celsius to obtain a pure culture before being removed from the medium. After the distinct colonies were transferred aseptically, they were streaked onto slants and incubated for an additional 5 days at 37 °C. This process was repeated five times. The pure colonies were stored in the refrigerator at 4 °C until needed for characterization and identification (Tafinta *et al.*, 2013).

Characterization and Morphological identification of fungal isolates

The pure colonies of the fungal isolates were distinguished from one another by analyzing their macro- and micro-morphological characteristics in accordance with Tafinta *et al.* (2013). To carry out the morphological identification, cultural characteristics were considered. These characteristics included spore shape, septation, colony morphology, and pigmentation. Using a sterile inoculating needle, thin smears of the mycelia were prepared on a glass slide for microscopic investigation. This was done in order to ensure no contamination. Following the methodology outlined by Oyemeachi *et al.* (2014), these smears were stained with a drop of lactophenol-cotton blue solution. The identification was performed by exploiting photomicrographs of fungi published in 1988 by Robert and Ellen. During microscopic identification, the components considered were the size, shape, surface properties of the conidia, and the arrangement of the hyphae.

Percentage of Bacterial and Fungal Occurrence

A calculation was performed for each microorganism to determine the percentage of different bacterial and fungal isolates present in the culture. The frequency of occurrence for each isolate was also recorded and expressed as a percentage of the culture.

$$\text{Percentage of occurrence} = X/N \times 100\%$$

Where, X= Total number of each organism in all the onion waste,

N= Total number of the entire organisms in all the samples screened.

Construction of the Single-Chamber Microbial Fuel Cells

The electrodes used in this research are copper and zinc, each with a total area of 78.50 square centimeters. Copper (Cu) was used at the anode of the microbial fuel cells, while zinc (Zn) was utilized at the cathode of the cells. When the three microbial fuel cells were created

simultaneously, the proton exchange membrane (PEM) was absent in all processes, allowing natural flow and ion exchange and achieving high performance without limitations (Cecconet *et al.*, 2018). The MFC chamber consisted of a 1000-milliliter polymethyl methacrylate tube. One end of the tube had a 5-centimeter hole drilled into it to ensure the cathode was in contact with the oxygen (O₂) in the environment. They were connected via an external resistance attached to a copper wire with a diameter of 0.2 centimeters to an ammeter and a Galvanometer. The electrodes had a total area of 78.50 square centimeters and were linked. The set up is shown in Plate 2.



Plate 2: Single Chamber Microfuel Cell connected to Ammeter and Galvanometer

Characterization of Microbial Fuel Cells

Measurements were taken using a multimeter (Prasek Premium PR-85-USA) at 22 ± 2 °C over a period of two weeks. The voltage and current generated were recorded. An external resistance of 1000 ohms was used. A conductivity meter, model CD-4301, monitored conductivity changes, which allowed for the calculation of both current density (CD) and power density (PD). Power was calculated by multiplying voltage by current. Two equilibrium equations were used to estimate power density: $P = V \times I/a$ of the electrode, and $V = I \times R$. These equations include three variables: P (power density in milliwatts), V (potential in volts), and I (current in milliamperes). The pH was measured with a pH meter. To determine the resistance values of the MFC, an energy sensor was employed for measurement.

Isolation of an Electrogenic Microorganism in an Anodic Chamber

After collecting a swab from the anode plate, the sample was cultured on media containing Brain Heart Infusion Agar, Nutritive Agar, MacConkey Agar, and Sabouraud Agar. Incubation at 36°C was necessary to isolate Gram-negative bacteria, while fungi and yeasts required incubation at 30°C. This process was repeated three times in total (Haruna *et al.*, 2023; Hindatu *et al.*, 2017).

Data Presentation

The data points for voltage, current, pH, and power density (PD) were averaged from three replicates, and the error bars represent the corresponding standard deviations. These data points were displayed in tables, charts, and figures in the presentation. The values obtained came from three replicates.

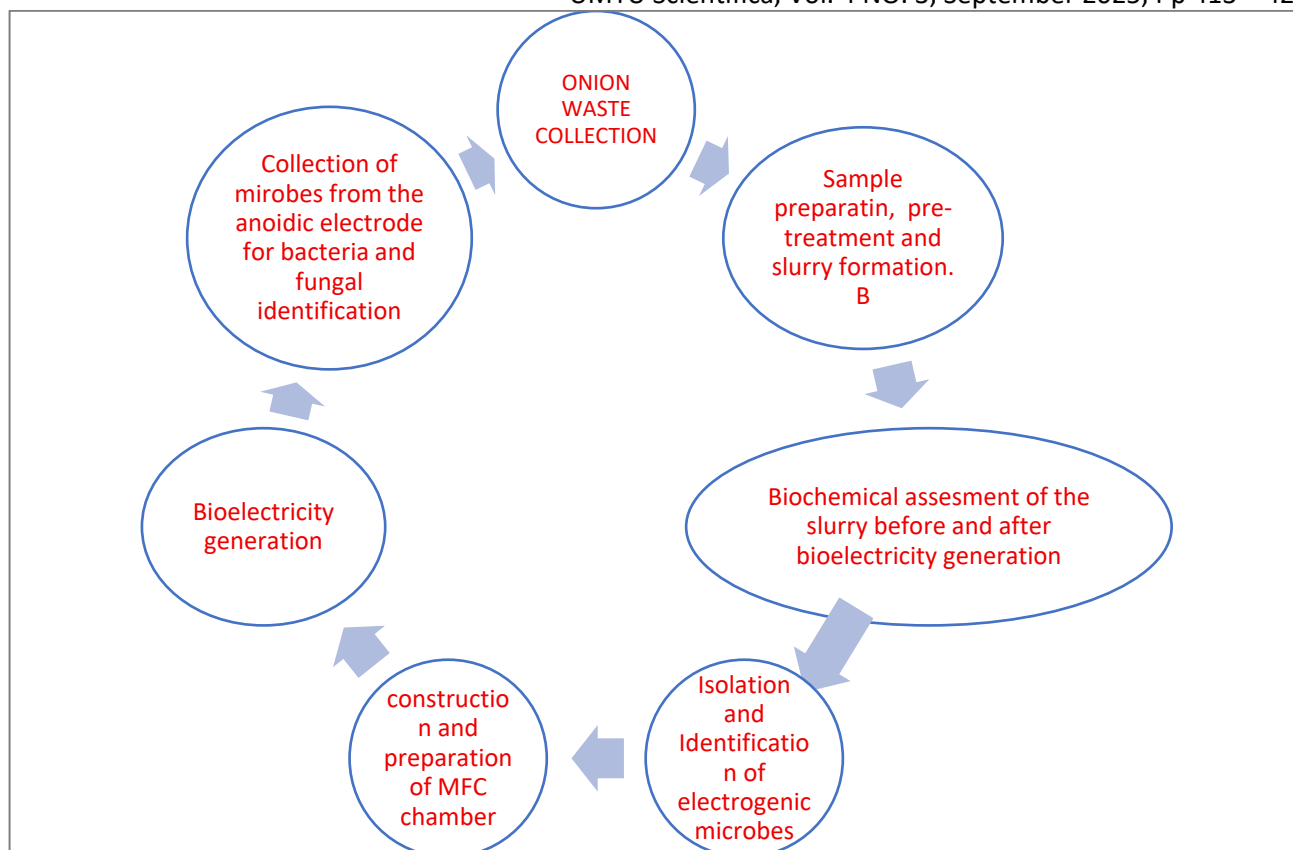


Figure 1: Work flow of the research

RESULTS AND DISCUSSION

Nutritional composition of onion waste before and after bioelectrical assessment

Table 1: Nutritional composition of onion waste before and after bioelectrical assessment

Nutritional composition	Samples (%)	
	Initial stage	After
Ash	2.00+0.35 ^a	1.50+0.35 ^b
Carbohydrates	0.40+1.52 ^a	2.55+1.52 ^b
Lipid	1.50+0.70 ^a	2.50+0.70 ^a
Moisture	90.50+2.12 ^a	87.50+2.12 ^b
Nitrogen	0.90+0.04 ^a	0.95+0.04 ^b
Protein	5.60+0.25 ^a	5.95+0.25 ^b

The nutritional content was high at the beginning of the trial (Table 1), and the electrical characteristics were higher than on the fourth and fifth days of the experiment. This was in comparison to the beginning of the investigation. Due to the increased microbial activity and fermentation, the current and voltage were significantly higher during the middle part of the study, specifically days 4-6. This was due to strong fermentation activity. Because voltage variability depends on the availability of organic wastes, inorganic elements, and oligoelements in vegetables, as well as on the selection and growth of microorganisms and the average temperature, this is consistent with the findings of Haruna et al. (2023). To maintain their existence, microbes utilize the energy generated by the oxidation of organic substances, as observed and reported in prior research. Logrono et al. (2015) state that they are

responsible for converting the stored energy into electrical power.

Frequency of Occurrence of Electrogenic Fungi in Onion waste

Based on microscopy, macroscopic examination, Gram staining, and biochemical testing, the onion waste sample contains a variety of fungi and bacteria. The rotting onion samples were used to isolate six different fungi. The presence of *Rhizopus stolonifer*, *Aspergillus flavus*, *Candida tropicalis*, *Aspergillus fumigatus*, and *Penicillium* spp. is indicated by this (Table 2). According to Tafinta et al. (2013) and Dunaski et al. (2022), these are among the most common fungi found infecting foods. This is because they occur most frequently in vegetables, such as oranges and rotten tomatoes, across all six markets. This finding aligns with the results of Akinmusire (2011), Bello et al. (2016), and Ibrahim et al. (2011), who reported that *Aspergillus niger* was the most common fungus in their studies. Samuel and Orji (2015) found that the predominant fungi in rotting onion samples were *Rhizopus stolonifer*, *Aspergillus flavus*, and *Aspergillus fumigatus*. This matches the current findings, indicating that both *Aspergillus* and *Saccharomyces* species are present. It has also been shown that *Rhizopus stolonifer* and *Aspergillus flavus* are responsible for rotting oranges (Tafinta et al., 2013), avocados and pears (Chukwu et al., 2008), and tomatoes (Lydia, 2015). *Aspergillus flavus* is one of the fungi that causes browning in tomatoes. The study revealed that bacteria are the primary microorganisms responsible for the deterioration of onions. The fungal isolates are shown in Plate 3.

Table 2: Frequency of Occurrence of Electrogenic Fungi in Onion Waste

Isolate	Observed Diagnostic Macroscopic Features	Observed Diagnostic Microscopic Features	Name of the Species Identified	Frequency of occurrence	% of occurrence
1.	Greenish brown flat colony	Brown septate conidiophore with club like conidia	<i>Alternaria alternata</i>	7	20.00
2.	White compacted conidia, change to black with pale yellow edges producing radial fissures	Conidia appear dark and radial with septate hyphae	<i>Aspergillus niger</i>	12	34.29
3.	White and Pink cotton or woolly colony	Filamentous septate transparent hyphae	<i>Fusarium oxysporum</i>	6	17.14
4.	Blue-green powdery velvet	Round ovoid conidia with septate hyphae	<i>Penicillium digitatum</i>	4	11.43
5.	White-grey cotton like colony	Branched mycelia with nodes and internodes	<i>Rhizopus stolonifera</i>	4	11.43
6.	Cream-yellowish, spherical shape	Ovoid and spherical shape buds or colony	<i>Saccharomyces cerevisiae</i>	2	5.71



Plate 3: Fungal Isolates

Table 3: Morphological features of the Bacterial isolate present in onion waste

Samples	Microscopic Characteristics							Biochemical Characteristics							Identified Isolates	
	Morphological feature	Gram Reaction	Shape	Gas	Sulp	Lac	Cat	H ₂ S	Coa	Mot	Cit	Ure	In	Mot. Rate		Vp
A	Large colony milky, rough edge (LCMR)	Gram -ve	Short rods	+	-	-	-	-	+	+	+	+	-	-	+	<i>Aeromonas veronii</i>
B	Small colony, milky smooth edge (SCMS)	Gram +ve	Cocci with central spores	+	+	-	-	-	-	+	-	+	-	-	+	<i>Micrococcus varians</i>
C	Large colony, white rough edge (LCWR)	Gram +ve	Long rods with terminal spores	+	-	-	-	-	+	+	+	+	-	-	+	<i>Bacillus subtilis</i>
D	Small colony milk smooth edge	Gram +ve	Short rods	+	+	+	-	-	-	+	-	+	+	-	+	<i>Corynebacterium kutscheris</i>
E	Large colony with milky, rough edges	Gram +ve	Cocci in chains with terminal	+	+	+	-	-	-	+	-	-	-	+	-	<i>Micrococcus varians</i>
F	Small colony, milky, rough edges	Gram +ve	Cocci in a cluster	+	+	+	+	-	-	+	+	+	-	+	-	<i>Proteus mirabilis</i>
G	Large colony with a white, smooth edge	Gram +ve	Short rods in chain with central spore	+	+	+	-	-	-	+	-	-	-	+	-	<i>Streptococcus pyogenes</i>
H	Large colony with white, rough edges	Gram -ve	Short rods	+	-	-	-	+	+	+	+	+	-	-	+	<i>Aeromonas hydrophilia</i>
I	Small colony with white, smooth edges	Gram +ve	Short rods with central spore	+	-	-	-	-	-	-	-	-	-	+	-	<i>Micrococcus luteus</i>
J	Large colony with white, smooth edges	Gram +ve	Cocci	-	-	+	-	-	+	+	+	+	-	+	-	<i>Enterococcus faecalis</i>
K	Large colony with milky smooth edges	Gram +ve	Cocci	+	-	+	-	-	-	+	-	+	-	+	-	<i>Micrococcus varians</i>
L	Small colony with milky smooth edges	Gram +ve	Cocci	+	-	-	-	-	+	+	+	+	-	+	-	<i>Staphylococcus aureus</i>



Plate 4: Bacterial isolates

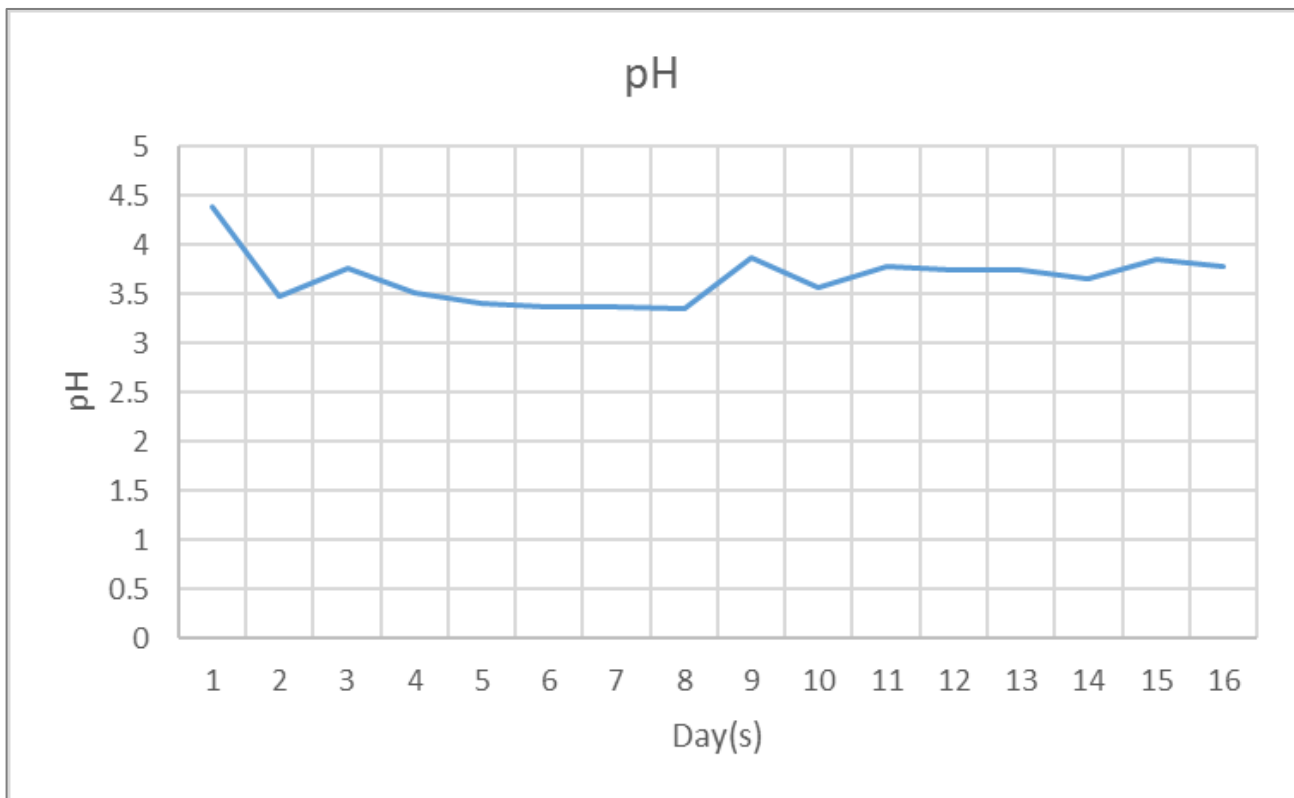


Figure 2: pH of the onion waste slurry for Bioelectricity generation

Isolate and Identified Bacteria in onion waste

The study identified twelve different bacterial isolates (Table 3), with *Staphylococcus aureus* and *Escherichia coli* being the most common in the environment. These bacteria were also found in rotting tomato samples, as reported by Chukwu *et al.* (2020) and Oyemaechi *et al.* (2014). Gosh (2009) and Oyemaechi *et al.* (2014) explained that microbial contamination can result from various factors, including excessive moisture, the use of organic manure,

poor handling hygiene, and other unfavorable conditions. This was further supported by Al-Hindi *et al.* (2011) and Mathew (2011), who studied tomato contamination and suggested that factors such as bruised or damaged fruits during harvest, cross-contamination, or contact with pathogens during transport may lead to bacterial growth and fruit spoilage. Lemma (2002) and Omolaran *et al.* (2016) have noted that bacteria are opportunistic pathogens, while fungi remain the most damaging, causing spoilage of fruits and vegetables.

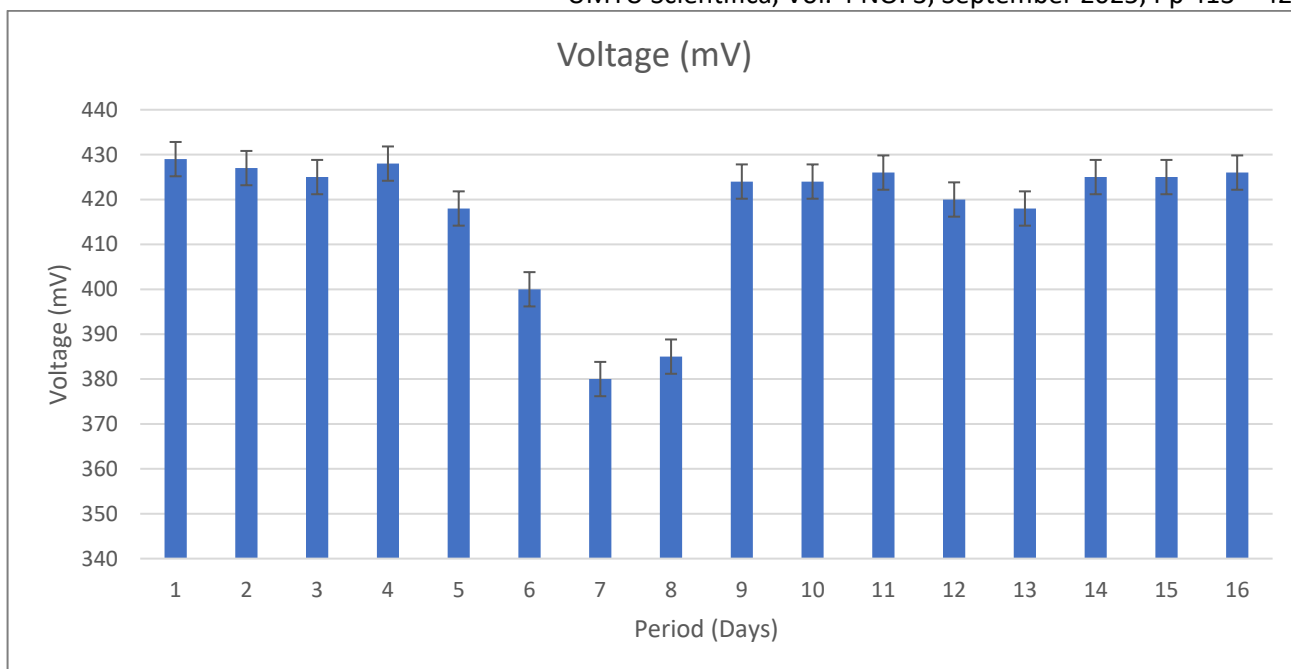


Figure 3: Voltage Generated from Onion Waste for Electricity Generation

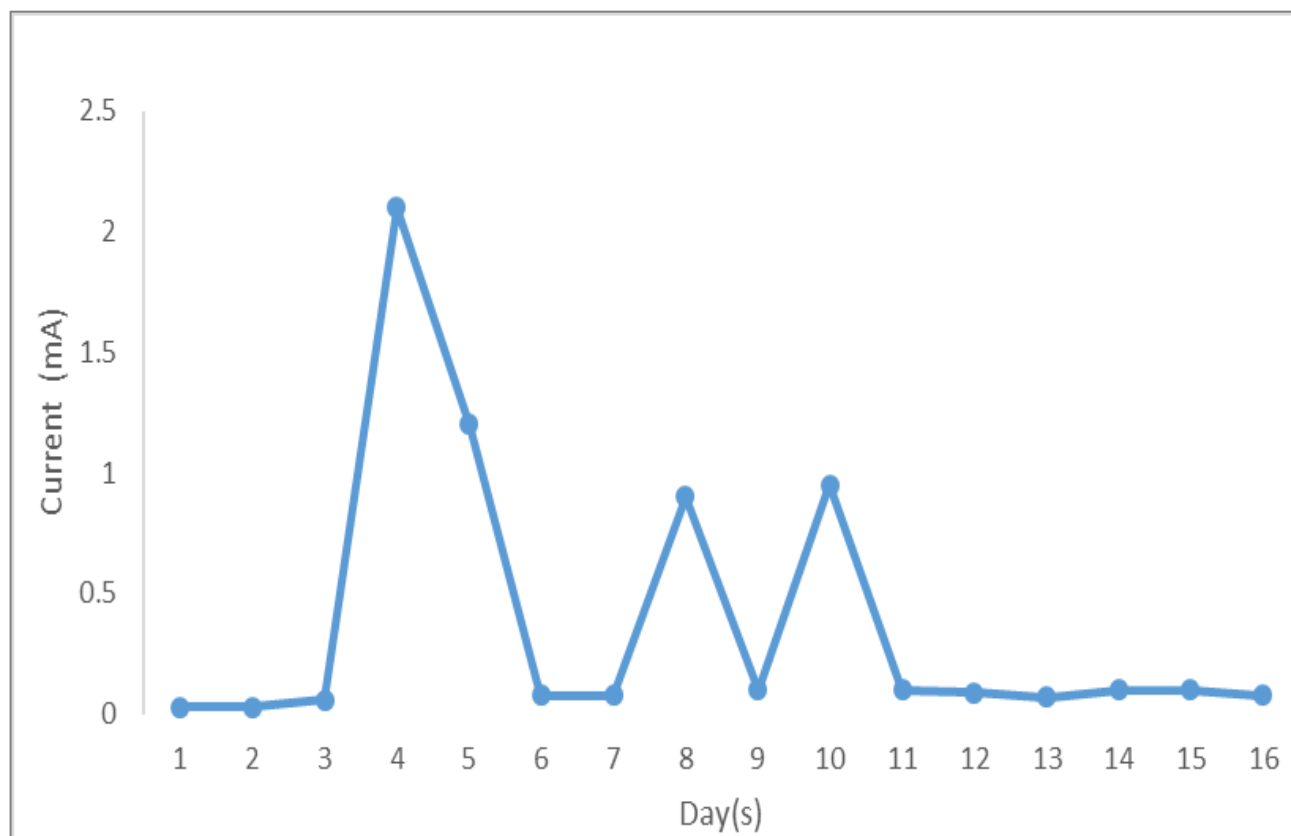


Figure 4: Current generated from the Onion waste

According to *Olivieri et al. (2004)*, bacteria causing cherry fruit rot produce a wide range of hydrolytic enzymes that facilitate fermentation. These include proteases, cellulases, pectinases, and xylanases. *Aveskamp et al. (2008)* demonstrated that these enzymes cause tissue maceration and cell death. Once this occurs, the microorganisms can access nutrients stored within the dead plant tissues. The bacterial isolates are shown in [Plate 4](#).

pH of the onion waste slurry for Bioelectricity Generation

Despite the pH level's tendency to become more acidic (3.23), this indicates that the electrolyte possesses desirable features; however, it is unfavourable for bacterial metabolic activities. Both *Haruna et al. (2023)* and *Guo et al. (2020)* observed that substrates become more acidic as the concentration of protons (H⁺) in the electrolyte increases. This is something that has been brought to light by both of these groups. This occurs as a direct result of

the metabolic processes that are carried out by the electroactive microorganism. The pH tends to drop to 3.50, 3.40, and 3.30 at specific times throughout the day, as shown in Figure 2, and the acidity of the substrate often increases during these periods. These variations in pH are characterized by a reduction in pH. A reduction in pH is indicative of sustained microbial activity and the concomitant metabolic reaction within the electrolyte, as reported by Haruna *et al.* (2023).

Electrons and hydrogen ions (H⁺) are typically generated during the anaerobic breakdown of organic materials by these bacteria. This process is carried out in the absence of oxygen. These H⁺ ions, as stated by Puig *et al.* (2010), are responsible for the solution's acidity, which, in turn, lowers its pH. Zhang *et al.* (2009) proposed that several components in the substrate are the root cause of the

observed pH fluctuations. Components such as the microbiota and structural components, like glucose, which has the ability to serve as a source of energy, are included in this category. This is because there is an optimal pH that achieves the best production performance, and any deviation from this ideal pH leads to the cessation of production (Puig *et al.*, 2010). The pH, on the other hand, may influence these microorganisms' capacity to generate bioelectricity. This is because several microbial groups are capable of growing on the substrate. According to Rojas-Flores *et al.* (2021), pH affects bioelectricity generation because, at low pH, the electrical properties of agricultural waste (such as tomatoes and onions) used for bioelectricity generation are higher. Same observations were made in potato waste and orange peel. Moreover, at neutral pH, the material's electrical properties decrease, rendering it inactive.

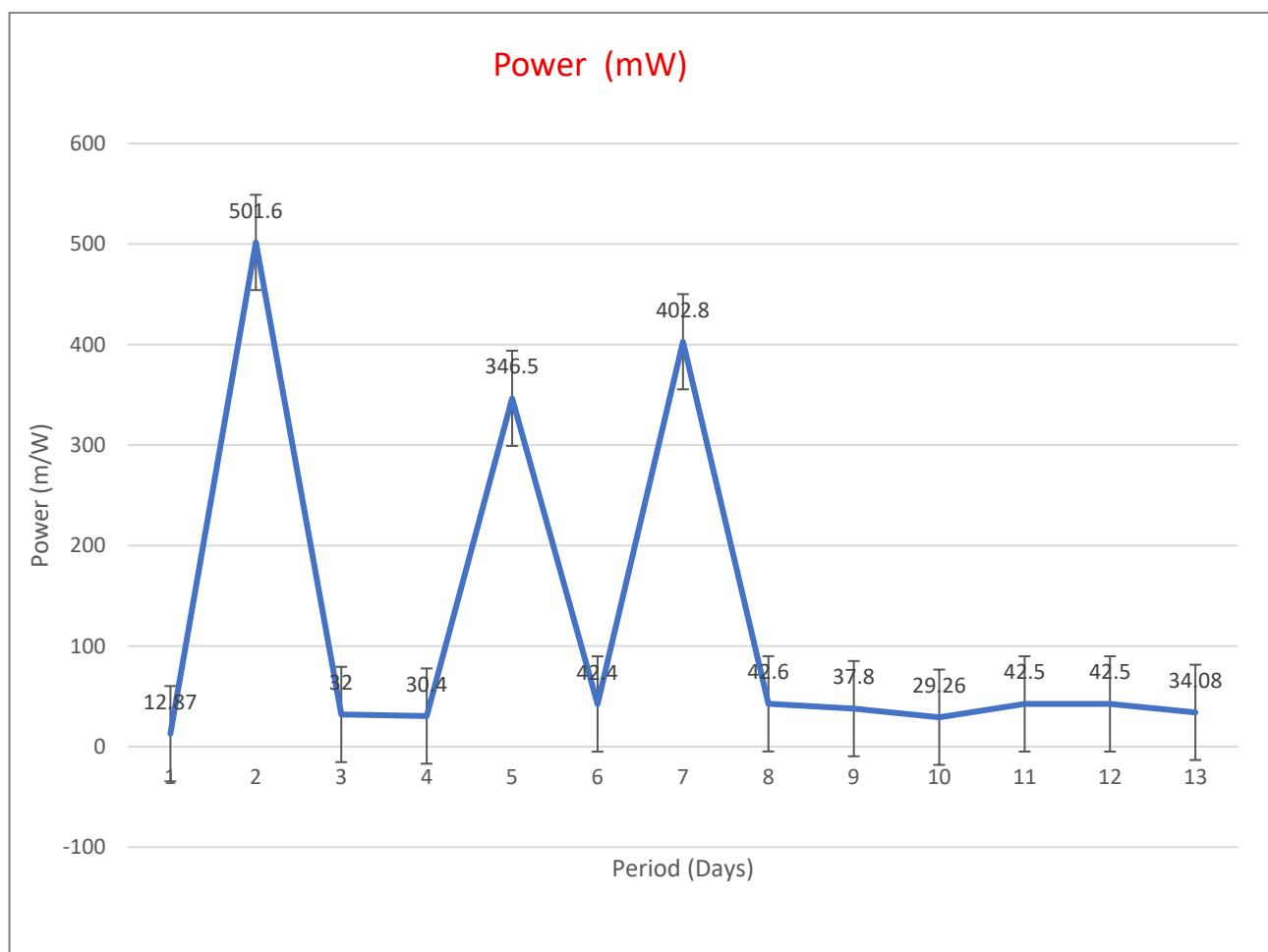


Figure 5: Power generated from Onion waste

Bioelectricity Generated from Onion Waste for Electricity Generation

The voltage generated from onion waste exhibits a continuous decrease in current, voltage, and power density, which is influenced by various factors, each of which can affect the outcome depending on the circumstances. This is something that could not be clearer. The thickness of the biofilm (Logan *et al.*, 2006), the depletion of substrates (Logan *et al.*, 2006), the accumulation of metabolites (Logan *et al.*, 2006), the loss of the active microbial population (Logan and Regan,

2006), the changes in pH (Rabaey and Verstraete, 2005), and the competitive microbial processes (Lovley, 2006) are some of the factors that contribute to the microbial community. Furthermore, it is essential to emphasize that the current was generated by the transfer of electrons produced by the metabolism of the fermentative bacteria present (Richter *et al.*, 2008).

At seven (7) and eight (8) days, the chemical and nutritional composition of the onion waste sample was depleted, halting the majority of the microbial activities the bacteria carried out. There are organic and inorganic

components present in onion waste, which cause the observed rise and reduction in the voltage and current characteristics of the onion waste slurry (electrolyte/bioenergy). These qualities result from the availability of these elements. The voltage, on the other hand, was found to decrease with increasing number of days, as expected. The result shown in Figure 3 reveals that the microbial fuel cell exhibited the highest electrical conductivity on the first day, at 429 mV. This was brought to light by Rojas Flores *et al.* (2021), who pointed out that the result was displayed. The presence of this signal indicates that the fuel cell generated a significant quantity

of electrical power. The current has increased by 02.1 milliamperes on the third and fifth days of the experiment. According to all measurements taken throughout the study, which exceeded 400 mV, the voltage fluctuated on the seventh day (380 mV) and on the eighth day (385 mV). The maximum voltage was produced during the first four days of the research (429 mV, 427 mV, 425 mV, and 428 mV), whereas the highest current was produced on the fourth day (2.1 mA) and the fifth day (1.2 mA) (Figure 4). This was the case in the present inquiry. This led to higher power densities of 898.8 mW and 501.6 mW, respectively (Figure 6).

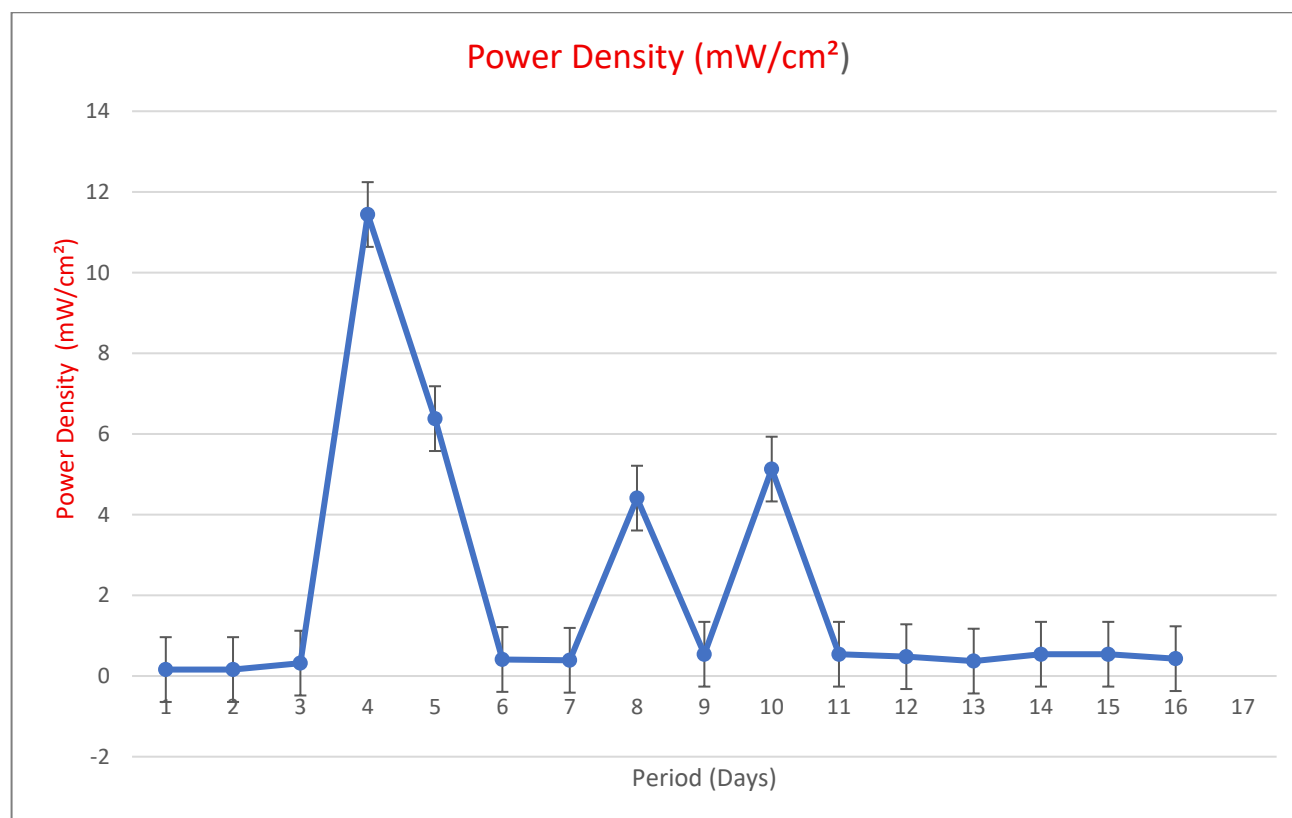


Figure 6: Power Density generated from Onion waste

Additionally, there was a decrease in microorganism activity, which may be related to changes in the substance's electrical properties. As a result of the biochemical analysis, the organic content of the onion waste slurry, which was the principal energy source for the electrogenic microorganisms, had decreased. This was in accordance with the findings of the inquiry. Segundo *et al.* (2022) observed that the current values for the substrates decreased in the last days of monitoring, a result consistent with their data. Following the acquisition of maximum power density, Abdolhossein *et al.* (2023), Bejjanki *et al.* (2021), and Sahu *et al.* (2019) all reached the same conclusion, observing the same phenomenon. The quantity of substrate decreased after five days, resulting in a decrease in the amount of power produced (Figure 5). This was the outcome of the decline in substrate quantity. For wastewaters from the sugar industry, Sahu *et al.* (2019) obtained results comparable to those described above. The open voltage was 1.42 V, the current was 23.66 mA, and the power density was 5.1 mW. Both the voltage and power density in this inquiry increased to greater values as

a result of adding glucose to the sample on day eight of the investigation. The electrical properties that were found to have been uncovered all showed a discernible improvement. The addition of glucose to the wastewater in the fed-batch system increased the amount of power produced, according to Abdolhossein *et al.* (2023). This suggests that bacteria in the wastewater were able to eat glucose as a substrate and produce enzymes to oxidize glucose.

The oxidation of glucose by microorganisms, which enhances the electron transfer for power generation, is evidence that microbes were already present in the wastewater. The oxidation of glucose by microorganisms increases the rate of electron transfer, which is the reason for this phenomenon. A finding remarkably similar to this one was discovered in research conducted on the tomato substrate by Fogg *et al.* (2015) and Shrestha *et al.* (2016). On the first two days, the cell that was based on potatoes had the strongest current; however, by the fourth day, it had declined drastically from its previous level. Once that threshold was reached, the current began to

gradually drop. This behaviour may be related to a decrease in the concentration of organic compounds, which are responsible for electron conduction (Nayak and Gosh, 2018). This behaviour is likely associated to the lower concentration of organic compounds.

The microorganisms responsible for fermentation also generate electricity through their role in the process. The substrate, the fuel fermented, is converted by these bacteria into many different compounds, including hydrogen, carbon dioxide, and short-chain organic acids. It is possible to generate energy while simultaneously forming reduced chemicals under redox conditions. This is a possibility. According to Takahashi *et al.* (2016), these substances are produced either through fermentation or by direct electron transfer between microbes and the anode surface. The anodic chamber is responsible for producing ions, which, together with the electrons that have been liberated, travel via the copper wire to the cathode chamber, also known as the electrode. While they are there, they react with the H⁺ ions in the waste, producing bio-H₂ gas.

Energy is generated by carrying out this operation. The delivery of electrons results in the formation of an electric current. This is due to the potential difference between the two electrodes. An organic substance undergoes oxidation, which eventually leads to reduction. Research has been conducted, and some of the studies included are Khan and Obaid (2015), Heijne *et al.* (2010), and Radi and Al-Fetlawi (2017). The current in onion-based cells, on the other hand, steadily rises from 10.2 mA on the first day to 24.7 mA on the final day (Rojesh Flores *et al.*, 2021). This is in contrast to the situation described above. Compared to cells based on onions, this is another aspect in which it differs from those cells. Research by Nwaokocha *et al.* (2021) using Nigerian corn starch wastewater as a substrate reported significantly lower current and power densities of 8.10 mA/cm² and 7.7 mW/cm², respectively, compared to the results of this experiment. These findings are consistent with the results of this analysis.

CONCLUSION

Onion waste slurry in a single-chamber Cu/Zn MFC achieved a maximum voltage of 429 ± 15 mV and power density of 501.6 on the sixteenth day of the experiment. The pH of onion waste remained within the acidic range of 3-4. According to the findings, the most common fungus was *Aspergillus niger*, while *Escherichia coli* was the most frequently occurring bacterium. The electrical properties of the onion waste were displayed. The waste products produced by onions are degraded as they undergo oxidation. This process leads to the release of electrons, which in turn enables the transmission of bioelectricity. Based on these results, the discarded onion has the potential to contribute to power production. On the other hand, certain limitations were found regarding the amount of power generated and the time required to produce it. To find solutions to these problems, further study is required. It may be feasible to improve performance by focusing on the continuous cultivation

and harvesting of electrogenic bacteria that grow rapidly. This would require knowledge of the electrical properties of onion waste, which could facilitate achieving these improvements. As more research is conducted, there is a possibility that it may lead to improved efficiency and performance. The study makes an important contribution to the ecologically responsible exploitation of waste materials for energy development, particularly bioelectricity. Future work should evaluate continuous-flow operation and techno-economic feasibility.

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