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Bioelectricity generation from white and yellow corn beads by using microbial fuel cell technology

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Abstract

The essential purpose of the study was to find out the specific amount of electricity that corn waste materials will generate and what MFC Technology set-up can generate a greater amount of electricity. Five separate trials for Tinigib Visayan White Corn *(Zea mays L. var. indentata)* and Yellow Corn *(Zea mays var. saccharata)* were made in the study. Different microbial fuel cell set-up trials were constructed to determine if the mass difference of substrate, air pump application, and size of stranded wire used to connect to the electrode affect the performance of MFC set- up in electricity generation. Results showed that the yellow corn variety has more average voltage output with 0.177 V compared to the white corn variety at 0.167 V after seven days of lab observations, testing, and data recording. Data were analysed and interpreted using an independent sample test of mean showing the voltage output generated between two corn varieties. Results showed that the two corn varieties are suitable substrates in MFC technology to produce alternative electricity generation. The factors mentioned above in designing MFC set-up are effective, but it needs more thorough study and experimentation to refine its model. In the size of stranded wire used in the MFC set-up, results showed that the 2 mm stranded wire has a greater effect in voltage output generation than 0.6 mm stranded wire set-up. On the other hand, the mass difference of substrate and the air pump application has variation in MFC voltage output generation.

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Introduction

Energy is critical to building a competitive and sustainable economy. Throughout postwar history, the issues faced by the energy sector have changed dramatically (Ravago *et al.*, 2018). A solid wellspring of power is expected to guarantee economies' seriousness, noticing that energy security is a significant segment of current economies. Nonetheless, accomplishing energy security is a test. It represents an incredible open door for private areas to acquire from the present circumstance (Zha, 2013). From 1989 to 1993, the country experienced 8 to 12-hour power outages, and force was apportioned (Alonzo *et al.*, 2016). Until now, electricity is still an essential input for all manufacturing systems and a necessity for all households today. Electricity consumption may cause an improved living style and aggravated environmental impacts due to inappropriate use (Zhang *et al.*, 2017). In recent years, agricultural consumption has become a vital pollution source. The problems caused by poultry and animal feces are attracting global attention (Liu *et al.*, 2015). The irregular straw burning and livestock excrement in the agricultural country have caused a series of environmental dilemmas (Wang *et al.*, 2015). Research at home and abroad noted that all kinds of agricultural wastes, especially poultry, animal feces, and crop straw, have a very high nutrition potential and can also improve soils' sustainable production ability (Ibrahim, 2015). Therefore, the effective transformation of agricultural waste recycling and utilization was significant in controlling environmental pollution.

Biomass can be utilized energetically by creating electricity, heat, and fuel. There are different research areas around human health consequences of the use of biomass for energetic purposes. Some papers examine the existence of respiratory diseases caused by the domestic burning of biomass for cooking and heating, primarily in developing countries (Freiberg *et al.*, 2018). Due to the extensive availability of biomass worldwide, mainly because it can be collected as a by-product of many industrial and agricultural means, biomass represents a growing renewable energy source with high growth potential (Li, Rezgui and Zhu, 2017). One of the main characteristics of biomass that makes it become an energy source is that through immediate combustion, it can be burned in waste transformation plants to generate electricity or in boilers to generate heat at industrial and residential levels (Perea-Moreno *et al.*, 2018).

Bioenergy is defined as renewable energy that is produced from biomass. Organic materials such as trees, plants, and waste matter come under the broad area of biomass. Bioenergy has received significant interest in recent times because of the fast growth of fuel prices, fast fossil fuel reduction, environmental degradation by fossil fuels, and global climate alteration. A feedstock relates to a material that serves as the basis for manufacturing another product (Srinivasan, 2016). In 2016, the entire global capacity of renewables was 2,006,202 megawatt, with a share of 109,731 megawatts produced by bioenergy (IRENA, 2017). Biomass can be used energetically by generating electricity, heat, and fuel. There are different study areas around human health consequences of the use of biomass for energetic purposes. Some papers investigate respiratory diseases caused by the domestic burning of biomass for cooking and heating, primarily in developing countries (Trevor *et al.*, 2014). The concern of health effects for humans caused by biomass use for power generation (by bioenergy plants) remains relatively unexplored.

MFC is a compact reactor that can spontaneously generate electricity from the biomass through microorganisms' metabolic activity (anaerobic oxidation). MFCs are potential devices to harvest bioenergy from the wastewater and concomitantly clean the wastewater, thereby reducing the operational costs of wastewater treatment by conventional methods. A simple MFC set-up consists of an anode in anodic chamber, cathode in cathodic chamber, separated by a proton exchange membrane (PEM). MFC operates on a principle that biocatalysts oxidize organic substrates in the anodic chamber and releases protons and electrons in the process and the generation of CO2 (Bhargavi *et al*., 2018).

Microbial fuel cells (MFCs) have garnered more attention recently and have shown promise in several applications, including wastewater treatment (Yakar *et al*., 2018), bioremediation (Berame *et al*., 2020; Rosenbaum and Franks, 2014), biosensors (Mekawy *et al*., 2018), desalination (Zhang *et al*., 2018) and as an alternative renewable energy source in remote areas (Castro *et al*., 2014). Thus MFC has great potential in the future for not only energy generation but has many different applications. MFC not only generates electricity but the source for energy generation is waste, which makes it more special compared to the traditional energy sources (Chhazed *et al*., 2019)

In this research, since corn is one of the staple crops and agricultural products available in the local communities, the white and yellow corn were tested to see if it is a potential source of bioelectricity generation in remote areas using localized microbial fuel cell technology.

Materials and Methods

Research design

Various concepts for this research were supported by different theories and substantial variables supporting the basis of the study. Biomass proceeding to the flow of electric generation needs significant conceptual ideas and preferred technological processes to achieve the study's goal.

The first box in the diagram above shows the corn waste's filtration after being soaked in water. The green boxes were the different processes required to proceed to the next step - the red arrows after the yellow boxes indicated after the procedure. Biomass gasification represents one of several renewable technologies that intend to ease overdependence on fossil-derived hydrocarbons. Biomass sources exhibit higher hydrogen and oxygen content but a lower carbon content when compared with coal, hence low levels of CO_2 emissions (Jayaraman and Gökalp, 2015). Pyrolysis produces gas or oil from carbonaceous materials using high-temperature thermal cracking via an external heat source without the supply of air or steam.

The conventional gasification technology uses partial combustion by controlling the amount of air to convert hydrocarbons into carbon monoxide, carbon dioxide, and hydrogen. Due to the high thermochemical reactivity of biomass char, the evolution of biomass gasification technology has been an area of rising interest over the past few decades. Traditionally, biomass is used in combustion for energy-related applications. The main application is biomass in utility boilers alone or co-fired with coal (Jayaraman and Gökalp, 2015).

Biomass can be pyrolyzed or gasified for producing liquid fuel or gaseous fuel such as methane, hydrogen, and carbon monoxide. Numerous researchers have pointed out that pyrolysis is a suitable technology with industrial views for biomass valorization since the method conditions can be optimized to maximize gas, liquid, and char (Wiedner *et al.,* 2013).

Materials used

These are the materials used in the study, namely: Analogue millimetre, 5" stranded wire 2 mm and 0.6 mm, empty gallon container (4 pieces), empty 1.5 litre container (4 pieces), 5" rubber hose (4 pieces), air pump, electrical tape, scissor, stirring rod, alcohol lamp, pinch of salt, stick glue, stainless steel mesh, hot plate, 1.5 kl yellow corn, 1.5 kl white corn, 4 litre distilled water, 4 litre tap water, 5 grams nutrient agar, and 500 ml beaker.

Equipment

The experiment has two schematic diagrams of localized microbial fuel cell technology. The first set-up is shown in Fig. 1, with two anode chambers that contain yellow and white corns have shared the same cathode chamber since there are only two air pumps available for the experiment. The flow is shown below, with 750 grams of white corn and yellow corn sharing the same cathode chamber, and 500 grams of yellow corn and white corn sharing the same cathode chamber.

For the second schematic diagram below, each corn waste material (anode) will have a separate cathode chamber, meaning all anodes in the experiment will no longer share the same cathode chamber and no air pump is inserted in this set-up. This is to test if a separate cathode chamber has a different result on the amount of electricity emitted by the corn waste.

For the third trial, another set-up was made with separate chambers for the cathode, but it was inserted with an air pump. This is to test if inserting an air pump to the set-up, which was absent in set-up two, could generate electricity different from set-up 2. For the fourth set-up, the stranded wire was replaced with 0.6mm in size, which is thinner than what was used in set- up one- three (2 mm), and the air pump was also removed. Replacing the size of the stranded wire would differentiate the electricity emitted by the MFC Technology.

To differentiate the result in set-up four if the air pump is inserted, the last trial was made to see a significant difference in setup four and five. An air pump was used to increase the efficiency of the electrical charges produced from bacteria to supply more oxygen.

Experiment procedure

Preparation of powdered corn waste

The corn beads waste has undergone different stages of refining to be used as a potential source for bioelectricity.

The waste corn beads were roasted using dry heat where hot air covers the corn beads, cooking it evenly on all sides with a temperature at least 150 °C (300 °F) from an open flame to another heat source turned into black. After roasting, the corn waste was pulverized using mortar and pestle or any materials that could turn the corn beads into powder. Corn powder was soaked into an ample amount of water. Water was removed by filtering it using a cloth to get the corn coffee residue and was stored in the empty food storage container.

Preparation of salt bridge (proton exchange membrane)

In making a saltwater bridge for localized microbial fuel cells, put 200 ml water into a 500 ml empty beaker and a hot plate was used to boil the water. While the water was boiling, five (5) grams of nutrient agar and a pinch of salt were added to the boiling water and dissolved the mixtures with constant stirring. Once the nutrient agar and salt dissolved with water, the beaker was set aside and let to be slightly cooled. Before the mixture completely cooled down, four (4) rubber hoses with 3 inches in length were obtained. One end of the hose was sealed with cellophane and electrical tape and the other open end was poured with 20 ml prepared mixture. The mixture inside the hose hardened and was ready to be used in MFC technology as a proton exchange membrane (PEM).

Preparation of localized microbial fuel cell technology (How is it assembled)

Five sets of MFC technology were made in this experiment, and each set-up was made with the following procedures: (1) 750 grams yellow and white corn and (2) 1250 grams yellow and white corn waste materials. First, one (1) empty container (anaerobic chambers) was obtained where the corn waste residue was stored and another empty plastic bottle for the aerobic chamber. Next, a hole was made on the side of two containers of the same size where the salt bridge (proton exchange membrane) was inserted, making the two containers connected through the salt bridge. The inserted salt bridge was sealed using stick glue to avoid leaking water and corn residue.

Once the set-up was done, 750 grams of pulverized corn waste residue was poured into the container and the other container was poured with 750 tap water. To get the electricity from the source, 6 inches of stranded wire was put into each container. This wire will be used in getting the amount of electricity emitted by the MFC Technology by attaching the multimeter. **S**ince the experiment has a different set-up in each trial, for those set-ups with air pump was used, a hole was made at the cover of the cathode chamber where the air pump hose was inserted.

To produce electricity, MFCs anaerobically oxidize biodegradable substrates, like waste materials or acetic acid derivation, producing electrical flow through extracellular electrons move to the anode.

A two-chambered MFC is perhaps the most well-known set-ups and consists of a cathode chamber and an anode chamber, isolated by a proton trade layer (PEM). Microorganisms are filled in the anode chamber, either as a biofilm or as a suspended culture. At the same time, the cathode is then presented to an electron acceptor to work with an electrical flow. The two cells are usually isolated by a PEM, permitting protons to move to the cathode (Krige, 2019).

How are the data analysed, determined and recorded?

Using a multimeter, voltage and resistance were recorded using Ohm's Law and the equation describing the power and calculating the current and power. It was measuring the voltage across the resistor by touching the clips attached to each end of the resistor. The centre container sets as cathode and the corn as anode. Making sure that the multimeter is set to its lowest setting because the voltage may drift continuously, so initial measurement was applied.

Results and discussion

Table 1 above shows the average voltage of the two corn varieties for trials two to five. The yellow variety has a 0.177 average voltage while the white variety has 0.167 V.

Table 1. The average voltage output of two corn varieties.

Corn variety	Mass (g)	Average voltage in each trial (V)				Average voltage for trial 2 to 5 (V)
		Trial 2 (no air pump, 2 mm wire)	Trial 3 (with air pump, 2 mm wire)	Trial 4 (no air pump, 0.6 mm wire)	Trial 5 (with air pump, 0.6 mm wire)	
Yellow	750	0.279	0.228	0.086	0.216	0.202
	1250	0.253	0.124	0.087	0.139	0.151
			Average voltage			0.177
White	750	0.259	0.112	0.126	0.139	0.159
	1250	0.243	0.069	0.091	0.299	0.176
			Average voltage			0.167

This shows that the yellow variety has greater average voltage output. But the difference is very little, 0.01 V., the little difference of voltage output, is due to the composition difference between yellow and white corn. According to Worley (2016), the only difference between the two varieties is that the yellow variety has beta carotene, giving more nutritional value than white corn.

Table 2. Independent sample t-test of mean between the two corn varieties in terms of the amount of electricity generated.

Test Variable	Corn Varieties	Mean	Standard deviation	Significant Value	Remark
Amount of electricity generated	Yellow	0.177	0.076	0.824	Not Significant
	White	0.167	0.087		

Tested at 0.05 level of significance.

This added beta carotene of the yellow corn variety may help increase its glucose content compared with the white variety. Another factor that could be attributed to the low voltage output of the substrate is that the desired properties of an anode (substrate) in an MFC should include excellent electrical conductivity, large surface area, and high bio-compatibility for bacteria colonization. At the anode chamber, where anaerobic conditions are present, the microorganisms generate gas that should migrate easily out of the system to avoid increasing pressure in the anode chamber. Hence the need for a high bed void fraction is of paramount importance (Shanmuganathan and Rajasulochana, 2018).

Table 3. The average voltage is generated by two set-ups, with or without an air pump.

Corn Variety	Mass (g)	Average voltage in each trial (V)			
		Trial 2 (no air pump, 2 mm wire)	Trial 3 (with air pump, 2 mm wire)	Trial 4 (no air pump, 0.6 mm wire)	Trial 5 (with air pump, 0.6 mm wire)
Yellow	750	0.279	0.228	0.086	0.216
	1250	0.253	0.124	0.087	0.139
White	750	0.259	0.112	0.126	0.139
	1250	0.243	0.069	0.091	0.299
Average voltage (V)		0.259	0.133	0.098	0.198

In the study, the substrate was compact because the container size did not give a high surface area for bacterial colonization. Another study also suggested that the carbon-felt anode using a stainless steel mesh had a larger current output (Jung *et al.,* 2018), where the study did not apply/utilize. In this regard, there is no significant difference between the two corn varieties in terms of the output voltage. It also coincides with the results when data were analysed statistically as stated in Table 2 below.

Table 4. Comparison on the average voltage output on the use of two different sizes of stranded wire.

Corn Variety	Mass (g)	Average voltage in each trial (V)			
		Trial 2 (no air pump, 2 mm wire)	Trial 3 (with air pump, 2 mm wire)	Trial 4 (no air pump, 0.6 mm wire)	Trial 5 (with air pump, 0.6 mm wire)
Yellow	750	0.279	0.228	0.086	0.216
	1250	0.253	0.124	0.087	0.139
White	750	0.259	0.112	0.126	0.139
	1250	0.243	0.069	0.091	0.299
Average voltage (V)		0.259	0.133	0.098	0.198
		0.196		0.148	

With the *p*-value of 0.824, the null hypothesis tested at a 0.05 level of significance was not rejected. However, the difference in the voltage output of the two corn varieties needs more study to have strong evidence and establish the findings or discover more facts. In terms of the mass difference in corn substrate, the data in Table 1 above shows that in the yellow variety, the 750 g has the greater average voltage output, equal to 0.202 V, compared with the 1250 g, which is only 0.151 V. On the white corn variety, it is the other way around. The 1250 g corn white substrate has a greater average voltage output, equal to 0.176 V, compared with the 750 g, which is only 0.159 V. There is a bit of inconsistency in the data regarding the mass difference substrates for the two varieties. The two varieties should either support the smaller mass or the bigger mass in producing a greater voltage output. But the gathered data did not show that. This is certainly room for further study. The findings of Sun (2018) maybe can help shed light on the inconsistency. It showed in their study that when the feed of glucose concentration is changed from 0.5 g/L to 4.0 g/L the volumetric power density is decreased. When the glucose concentration is further increased to 12 g/L, almost no power output was observed. It is a fact that the more corn substrate put in the anode, the greater the concentration of glucose. Maybe the voltage output of the two corn varieties varies because there is a large amount of corn substrate, the 750 g and the 1250 g.

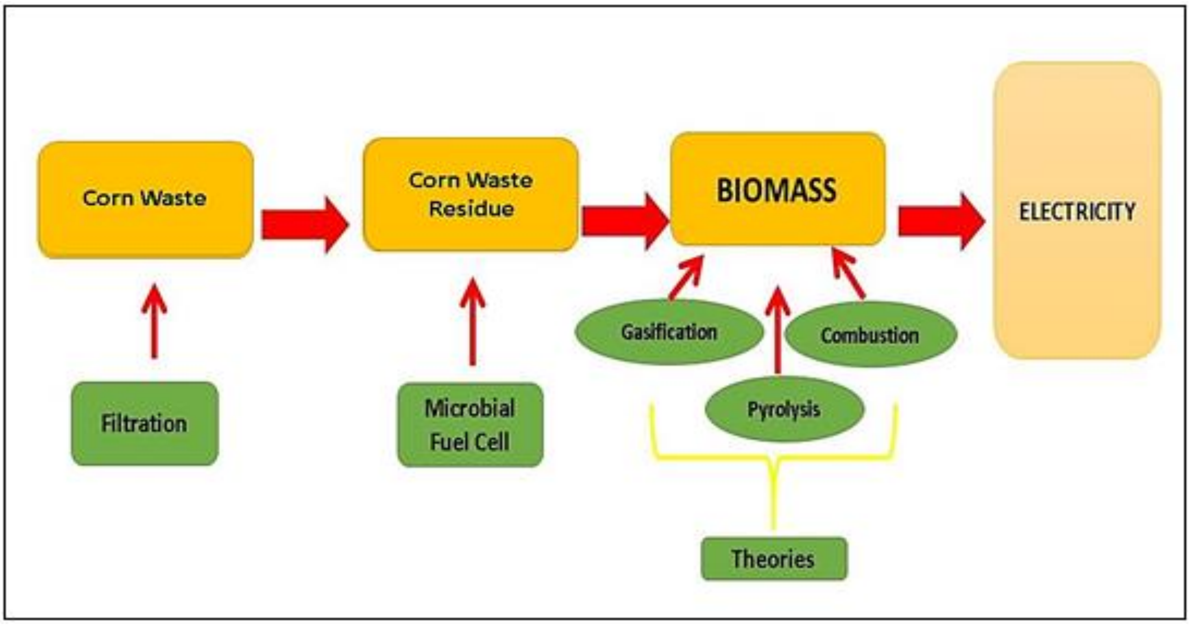

Fig. 1. Workflow of the research study.

Regarding air pump application on the MFC set-up, Table 3 below shows that the no air pump set-up has a greater average voltage output, which is 0.259 V, than with air pump, which is only 0.133 V for a 2 mm stranded wire set-up. Trials 2 and 3 are MFC set-up with 2 mm stranded wire that connects from the electrode. Trials 4 and 5 are MFC set-up with 0.6 mm stranded wire that connects from the electrode. For the 0.6 mm stranded wire set-up, again, it is the other way around. The set-up with an air pump has a greater average voltage output, which is 0.198 V, than with no air pump set-up, which is 0.098 V. Again, there is an inconsistency in the data when it comes to the air pump application in the MFC set-up. The two stranded wire sizes, namely 2 mm and 0.6 mm, should either support the set-up with an air pump or the set-up without the air pump in producing greater voltage output, but the gathered data has no evidence shown in the lab set-ups. This is another opportunity to investigate further.

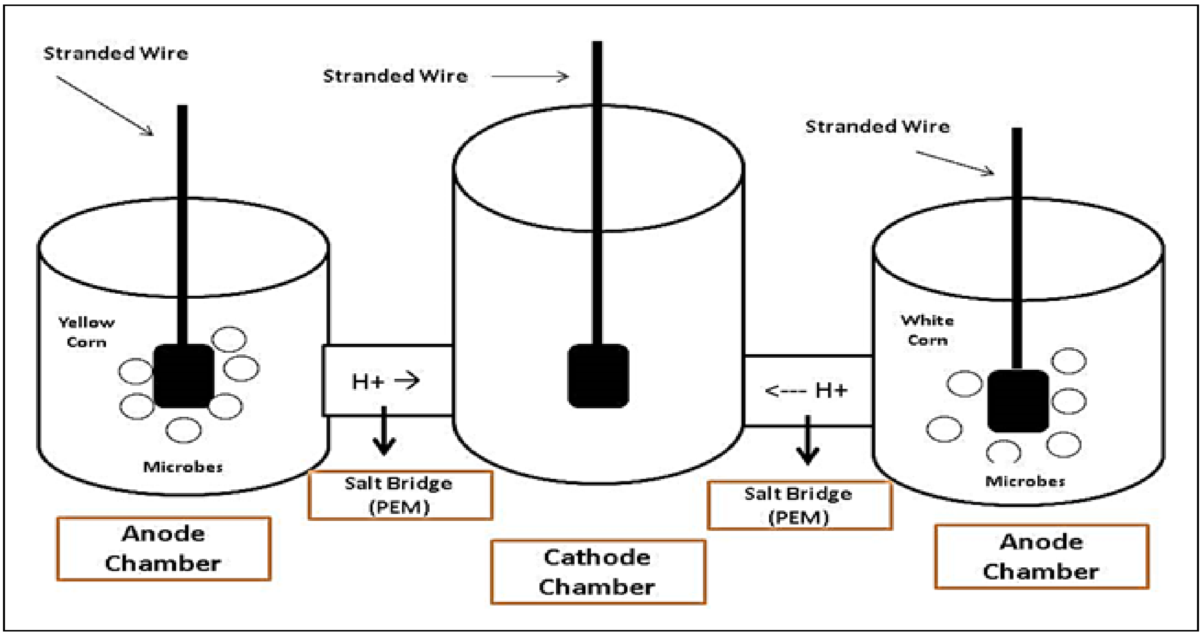

Fig. 2. First set- up of MFC Technology where both anode chambers share the same cathode.

The study conducted by Idris *et al.* (2016) showed an increase in voltage output of two-chambered MFC if an air pump is in the set-up. This finding corroborates with the data obtained from the 0.6 mm lab set-up. In terms of the difference in the size of the stranded wire used in the MFC set-up, Table 4 shows that the 2 mm stranded wire set-up has a greater average voltage output, which is 0.196 V, compared with the 0.6 mm stranded wire set-up, with only 0.148 V.

Their difference is 0.048 V which is very little. This difference needs further investigation to come up with strong evidence that this is so. However, voltage reversal could play as a hindrance.

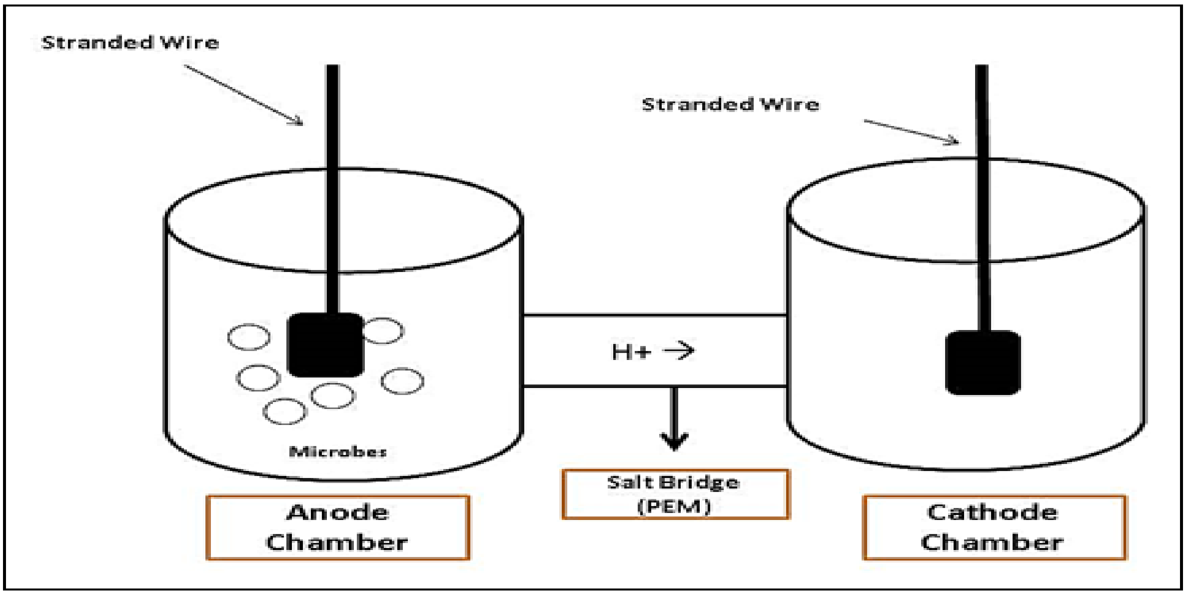

Fig. 3. Second set-up of MFC Technology where anode chamber has a separate cathode chamber.

The reason for the charge and voltage reversal can be attributed to the (i) absence of bacterial activity, (ii) depletion in the concentration of the substrate or fuel starvation at the anode, (iii) reduction in oxygen supply at the cathode, and (iv) poor water distribution in the membrane electrode assembly (Kiran and Gaur, 2013).

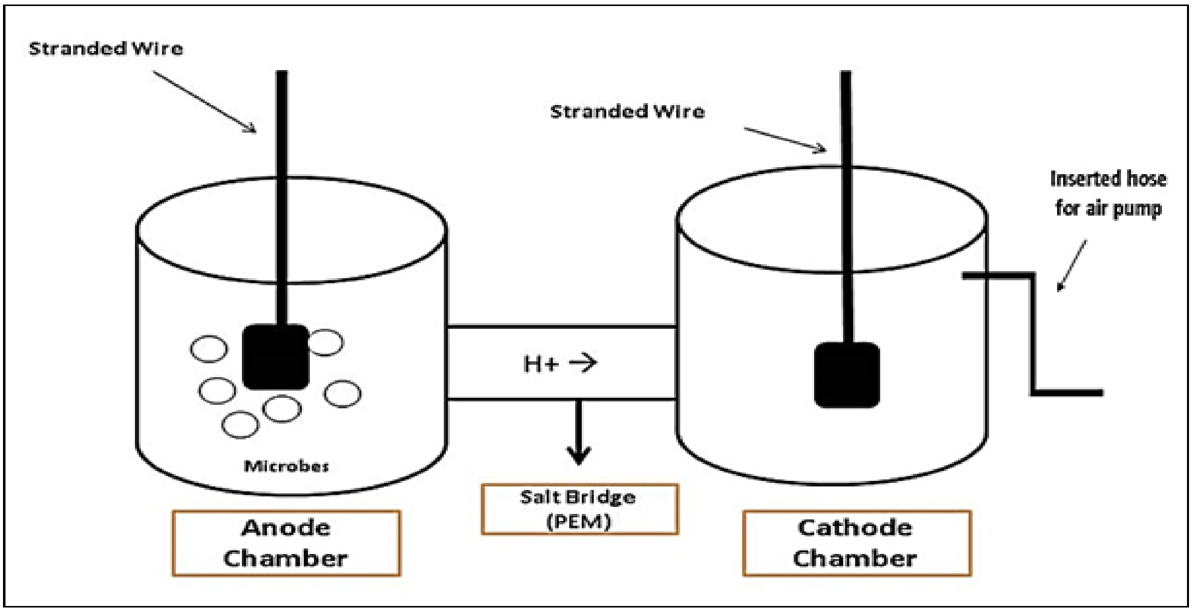

Fig. 4. Third set- up of MFC Technology where it has inserted with an air pump.

Many studies investigate what material is most effective to be used as an electrode in MFC technology but on the investigation on the effect of the size of wire that is used to connect the electrode, as far as the researchers are concerned, there's none. According to Jung (2018), there is greater electricity output of MFC if a larger current collector is advantageous in short-term performance but not beneficial when it's a long time. The study of Jung (2018) focuses on the effects of a specific type of anode current collectors in the MFC's performance in electricity generation. But it does not mention the importance of the connecting wires used from the electrode. Another study by Obileke *et al.* (2021) highlights the evaluation of different materials in MFC construction to its performance in electricity generation.

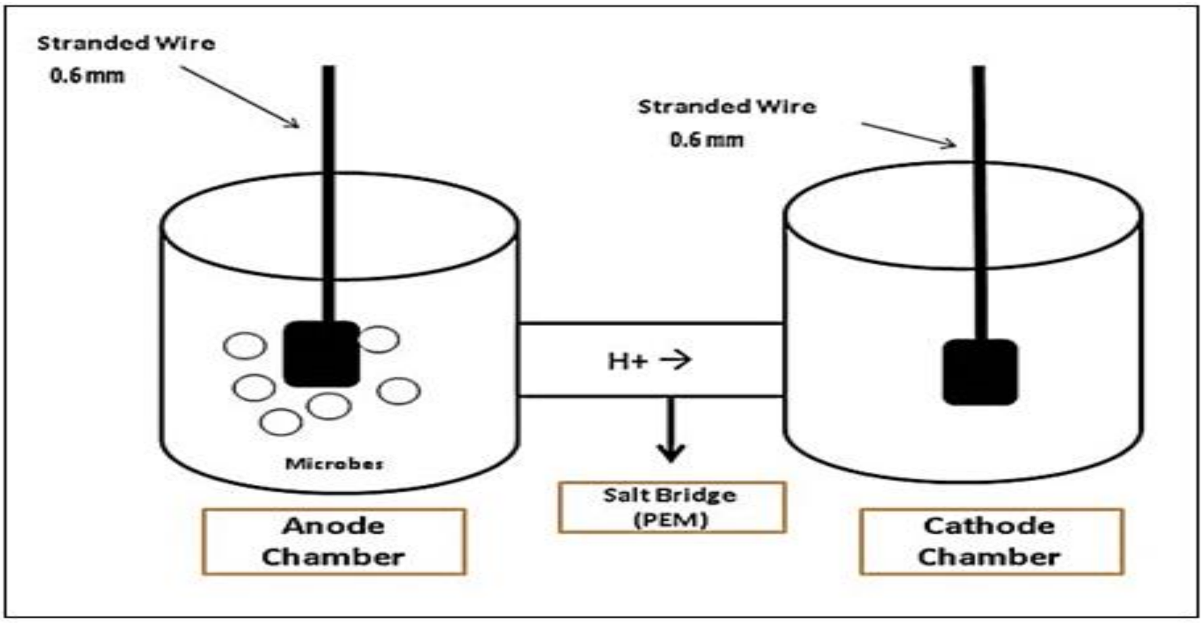

Fig. 5. Fourth set-up of MFC Technology with 0.6mm stranded wire and no air pump.

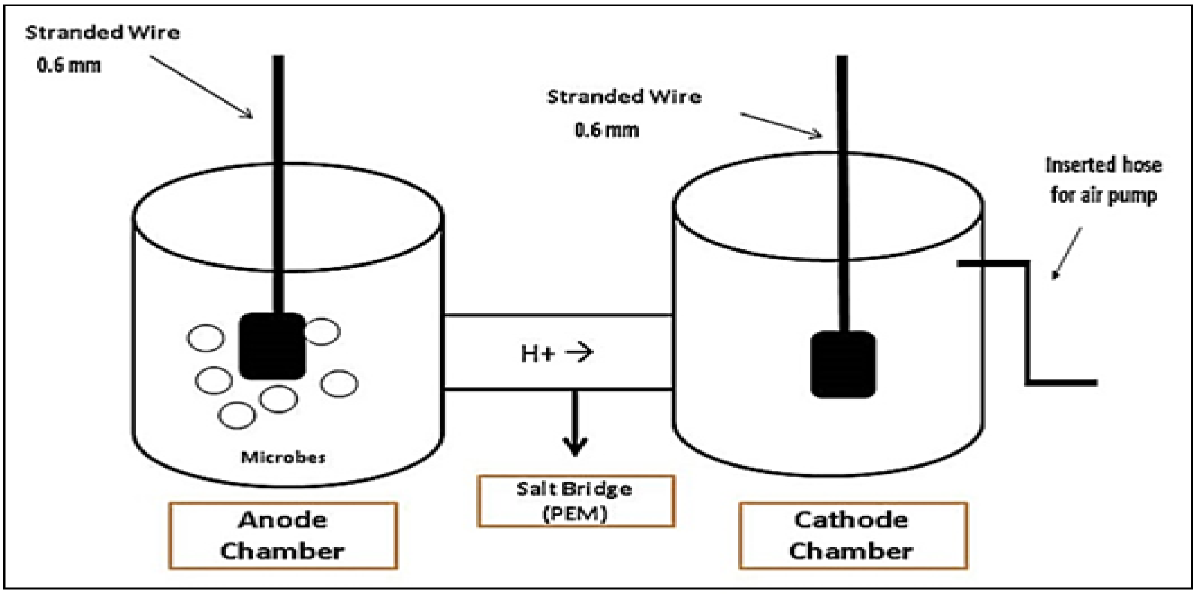

Fig. 6. Fifth set-up of MFC Technology with 0.6 mm stranded wire with air pump inserted.

This study reviews the latest and most relevant MFC articles and publications found at present. It revealed further in Obileke *et al.* (2021) the many common anode materials used in MFC and presents the advantages and disadvantages of each one. But it does not mention the effectiveness of the wire size to be used to connect the electrode in an MFC set-up. The two varieties of corn have generated different amounts of voltage during the experiment; the one with a lower amount of voltage should not be disregarded as not effective. Instead, the two varieties of corn effectively become an alternative source of bioelectricity, as reflected in the results above.

Conclusion

Based on the findings, two corn varieties have effectively emitted electricity. The mass difference of substrate (750 g and 1250 g set-up), air pump application, and stranded wire size (2 mm and 0.6 mm) affect the voltage output performance of the MFC set-up. Numerous factors affect the performance of MFCs. Despite the inconsistencies noted in the results, two corn varieties can be used as alternative electric power generation using localized MFC technology. The data obtained by the researchers were good sources of information for the future experiment on microbial fuel cells using corn beads as substrate in the lab set-ups. Further, more studies must be conducted to test whether other corn body parts will be suitable for microbial fuel cells. In addition, the period of observations can be prolonged to determine the maximum voltage output. Carbon felt should be attached to the stainless wire mesh. A large container must be used for a greater surface area for bacterial colonization in the cathode chamber. More influential factors on the generation of electricity in the MFC technology, operating conditions such as temperature, pH, and salinity should also be determined in the study. Finally, awareness of the efficient use of crop wastes as an alternative source of bioelectricity could help boost the minds of our young scientists to plan and conduct research in the future for bioenergy sustainability.

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References

Berame JS, Mariano MB, Lascano JP, Sariana LG, Macasinag ML, Alam ZF. 2020. Environmental biomonitoring of terrestrial ecosystems in the Philippines: A critical assessment and evaluation. International Journal of Ecology and Conservation **32,** 1-24

Ibrahim R. 2015. Tribological performance of polyester composites reinforced by agricultural wastes. Tribology International, **90**, 463-466. https://doi.org/10.1016/j.triboint.2015.04042

Idris SA, Esat FN, Rahim AA, Rizzqi WA, Ruzlee W, Razali MZ. 2016. Electricity generation from the mud by using microbial fuel cell, MATEC Web Conf. 69 02001. https://doi.org/10.1051/matecconf/20166902001

IRENA. 2017. Renewable capacity statistics. The International Renewable Energy Agency.

Jafary T, Ghoreyshi AA, Najafpour GD. 2010. The effect of substrate concentration on the electrical performance of microbial fuel cell. 2nd International Conference on Environmental Research and Technology at: Penang

Jayaraman K, Gökalp I. 2015. Pyrolysis, combustion and gasification characteristics of miscanthus and sewage sludge. Energy Conversion and Management **89,** 83-91. https://doi.org/10.1016/j.enconman.2014.09.058

Jung SP, Kim E, Koo B. 2018. Effects of wire-type and mesh-type anode current collectors on performance and electrochemistry of microbial fuel cells. Chemosphere **209,** 542-550. https://doi.org/10.1016/j.chemosphere.2018.06.070

Kiran V, Gaur B. 2013. Microbial fuel cell: technology for harvesting energy from biomass. Reviews in Chemical Engineering, **29(4).** https://doi.org/10.1515/revce-2013-0005.

Li Y, Rezgui Y, Zhu H. 2017. District heating and cooling optimization and enhancement-towards integration of renewables, storage and smart grid. Renew. Sustain. Energy Review **72,** 281-294.

Liu Y, Dong J, Liu G, Yang H, Liu W, Wang L, Kong C, Zheng D, Yang J, Deng L, Wang S. 2015. Co-digestion of tobacco waste with different agricultural biomass feedstocks and the inhibition of tobacco viruses by anaerobic digestion. Bioresource Technology **189,** 210-216. https://doi.org/10.1016/j.biortech.2015.04.003

Logan BE, Regan JM. 2006. Electricity-producing bacterial communities in microbial fuel cells. Trends in Microbiology **14(12),** 512-518. https://doi.org/10.1016/j.tim.2006.10.003

Logan BE, Regan JM. 2006. Microbial fuel cells-challenges and applications. Environmental Science & Technology **40(17),** 5172-5180. https://doi.org/10.1021/es0627592

Markandya A, Wilkinson P. 2007. Electricity generation and health. The Lancet **370(9591),** 979-990. https://doi.org/10.1016/s0140-6736(07)61253-7

Obileke K, Onyeaka H, Meyer E, Nwokolo N. 2021. Microbial fuel cells, a renewable energy technology for bio-electricity generation: A mini-review. Microbial fuel cells, a renewable energy technology for bio-electricity generation

Perea-Moreno MA, Manzano-Agugliaro F, Perea-Moreno AJ. 2018. Sustainable energy based on sunflower seed husk boiler for residential buildings. Sustainability **10,** 3407

Rabaey K, Boon N, Siciliano SD, Verhaege M. Verstraete W. 2004. Biofuel cells select for microbial consortia that self-mediate electron transfer. Applied and Environmental Microbiology, **70(9),** 5373–5382. https://doi.org/10.1128/aem.70.9.5373-5382.2004

Rabaey K, Clauwaert P, Aelterman P, Verstraete W. 2005. Tubular microbial fuel cells for efficient electricity generation. Environmental Science & Technology **39(20),** 8077-8082. https://doi.org/10.1021/es050986i

Rabaey K, Ossieur W, Verhaege M, Verstraete W. 2005. Continuous microbial fuel cells convert carbohydratesto electricity. Water Science and Technology **52(1-2),** 515-523. https://doi.org/10.2166/wst.2005.0561

Ravago ML, Brucal AZ, Roumasset J, Punongbayan JC. 2019. The role of power prices in structural transformation: Evidence from the Philippines. Journal of Asian Economics **61,** 20-33. https://doi.org/10.1016/j.asieco.2019.02.001

Rasool U, Srinivasan H. 2016. A review on bioenergy and biofuels: sources and their production. A Review on Bioenergy and Biofuels: Sources and Their Production.

Shanmuganathan P, Rajasulochana P. 2018. Factors affecting the performance of a microbial fuel cell. ECS Meeting Abstracts. Published. https://doi.org/10.1149/ma2005-02/6/280

Sun Y. 2018. Performance investigation of batch mode microbial fuel cells fed with high concentration of glucose. Biomedical Journal of Scientific & Technical Research **3(2).** https://doi.org/10.26717/bjstr.2018.03.000864

Torres CI, Krajmalnik-Brown R, Parameswaran P, Marcus AK, Wanger G, Gorby YA, Rittmann BE. 2009. Selecting anode-respiring bacteria based on anode potential: Phylogenetic, electrochemical, and microscopic characterization. Environmental Science & Technology **43(24),** 9519-9524. https://doi.org/10.1021/es902165y

Trevor J, Antony V, Jindal SK. 2013. The effect of biomass fuel exposure on the prevalence of asthma in adults in India – review of current evidence.

Journal of Asthma **51(2),** 136-141.
https://doi.org/10.3109/02770903.2013.849269

UNEP. 2009. Converting waste agricultural biomass into a resource. Compendium of Technologies.

Venkata Mohan S, Saravanan R, Raghavulu SV, Mohanakrishna G, Sarma P. 2008. Bioelectricity production from wastewater treatment in dual chambered microbial fuel cell (MFC) using selectively enriched mixed microflora: Effect of catholyte. Bioresource Technology **99(3),** 596-603.
https://doi.org/10.1016/j.biortech.2006.12.026

Wang S, Ru B, Dai G, Sun W, Qiu K, Zhou J. 2015. Pyrolysis mechanism study of minimally damaged hemicellulose polymers isolated from agricultural waste straw samples. Bioresource Technology **190,** 211-218.
https://doi.org/10.1016/j.biortech.2015.04.098

Wiedner K, Rumpel C, Steiner C, Pozzi A, Maas R, Glaser B. 2013. Chemical evaluation of chars produced by thermochemical conversion (gasification, pyrolysis and hydrothermal carbonization) of agro-industrial biomass on a commercial scale. Biomass and Bioenergy **59,** 264 278.
https://doi.org/10.1016/j.biombioe.2013.08.026

Worley S. 2016. What's the difference between white and yellow corn? Epicurious.
https://www.epicurious.com/ingredients/whats-the-difference-between-white-and-yellow-corn-article.