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Explore the Feasibility and Efficiency of Utilizing Plantaginaceae and Musaceae as Microbial Fuel Cell (MFC) as Fuel Source

Diwa James Enyia, Archibong Eso Archibong, Dane Osim-Asu, Maria Kaka Etete Enoh

Abstract: The conventional method of electricity generation, primarily relying on fossil fuels, have significant environmental and sustainability challenges. The widespread consumption of fossil fuels has led to the release of excess greenhouse gases (GHGs) and other toxic elements into the environment. Bioelectricity production using microbial fuel cell (MCFs) is an innovative and sustainable approach that harness the metabolic activities of microorganisms to generate electricity. This research encompasses the potential application of two species (plantain and cavendish banana) from the plant family plantaginaceae and musaceae, in microbial fuel cells (MFCs) for sustainable clean and green energy. Renewable energy Technology such as MFCs, have gained significant attention in recent years due to their potential to convert organic waste into electricity. The goal of this research is to explore the feasibility and efficiency of utilizing plantaginaceae and musaceae as a fuel source in MFCs. Three MFCs using Plantain sludge, Cavendish Banana sludge and SYSTEM 1 sludge as organic substrate for the anodic chambers were setup. The parameters considered were (A) substrate weight, (B) Time and (C) Temperature. Regression models were developed using Analysis of Variance (ANOVA) to predict the influence of study process factors A, B, and C, on current and voltage which are the Response (output). The actual values for current and voltage for the three MFC's were 68.4 µA and 81.9mV, 80.223 µA and 90.6mV, and, 73.65 µA and 90.67mV for Plantain, Banana and SYSTEM 1 Sludges respectively. The results show the values of the optimization for the currents and voltage of the three MFC's to be 67.7605 µA and 92.6117mV, 107.893 µA and 109.447mV, and, 73.4518 µA and 199.454mV using plantain sludge, banana sludge and SYSTEM 1 sludge.

Keywords: Bioelectricity, Microbial Fuel Cell, Microorganisms, Musaceae, Plantaginaceae, Renewables.

I. INTRODUCTION

Waste management is one of the major problems of the modern world, and this could be as a result of wastewater from industries, agriculture, and domestic sources and it has caused the world to delve into cost effective ways to remediate and also benefit from the process [1]. Also, the negative after-effect of fossil fuel in producing highly efficient power has led to the research on ways to achieve waste management and clean energy generation [2]. Electricity generation has greatly relied on the use of fossil fuels and the aftermath of this production of power has had negative consequences to environmental sustainability [3]. According to [4] Microbial electrochemical technologies represent a technology concept that allows exploiting the energy contained in Low- value biomasses (e.g. banana peels) as well as specific production of value-added products for a sustainable biotechnology. MFC is a bio-electrochemical device that converts chemical energy contained in organic substrates into electrical energy by the activities of microbes [2]. According to [1]. It offers sustainable green energy sources, and the research community is interested in this method actively because it uses waste material for the MFCs setup and biodegradable materials as fuel to run the system. The basic design of an MFC consists of an anode and a cathode compartment separated by a proton exchange membrane [2]. Microbes, typically bacteria, reside in the anode compartment and oxidize organic compounds, releasing electrons and protons [5]. The electrons flow through an external circuit towards the cathode compartment, creating a potential difference and generating electricity [6]. Meanwhile, the protons migrate through the membrane to the cathode compartment, where they combine with electrons and electron acceptors, typically oxygen to form water [6].

Although electricity generation plays a principal role in developing economies due to usage in different facilities and industries, it is a crucial contributor to global emissions of GHG resulting from fossil fuels [7]. Just as electricity is of great importance for developing economies, fruit consumption plays an important part in human dieting and high demands have been placed on such vital food commodities due to population growth [8]. The utilization of agricultural waste like banana and plantain peels to produce value-adding products serves as an effective method for waste management (since most agricultural wastes are readily available in the environment) and promotion of renewable energy such as electricity generation [9]. This study is aimed at addressing the negative effect of electricity generation from fossil fuel (turbines) and to explore the feasibility and efficiency of using peels from the Musa paradisiaca and Musa acuminata species in microbial fuel cells for clean and sustainable energy, which is more eco-friendly.

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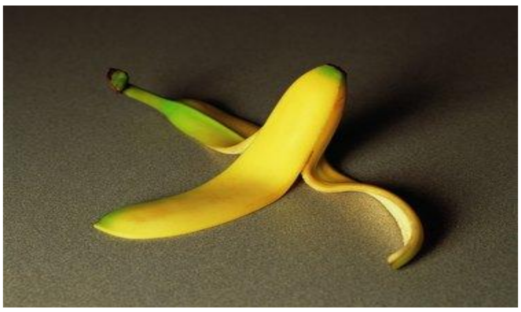
II. BACKGROUND REVIEW OF THE STUDY

The interest of evaluating and implementing renewable and sustainable alternative sources of energy to eliminate fossil fuel has been on the rampage due to it disadvantages to the society [10]. The increase in atmospheric carbon and global warming has called for concerns worldwide, as the use of fossil fuel have increased the level of carbon dioxide drastically [11]. This increase is harmful and could be from anthropogenic carbon emission resulting from burning fossil fuel [12]. The increased carbon dioxide is implicated as a cause of global warming from the effect of GHG, and it is further aggravated by other fossil fuel products like the nitrous oxides and incomplete combustion hydrocarbon [13]. The increase in sea level resulting from the melting of ice caps is caused by global warming [14]. This problem has the capability to cause flooding in coastal locations, but can be solved or prevented by reducing the size of the ice caps which reflects low energy into space. The increases in solar energy, increases global temperature, resulting in melting of more ice caps, which will amount to further increase in sea level [15]. One method of reducing the global warming is to reduce the emission of carbon to the atmosphere by applying carbon neutral and possibly carbon negative sources of fuel [16]. In MFC, microorganism oxidize substrate and transfer those electrons to an anode electrode. When the electrons flow through an external circuit, it creates a useable current and then reduce an oxidant at the cathode [17]. In this current research, Musaceae, known as the banana family, includes the genus Musa, which encompasses banana plants [18]. The Musaceae family comprises an important group of plants that includes bananas and plantain [25]. Plantain and banana as seen in Fig.1 and Fig.2, respectively are major staple crops in many regions, particularly in Africa, Asia and Latin America [20]. According to [19], they provide essential nutrients, including carbohydrates, dietary fibre, vitamins (such as vitamin C and vitamin B6), and minerals (such as potassium and magnesium) [26].

[Fig.1: Plantain Peels]

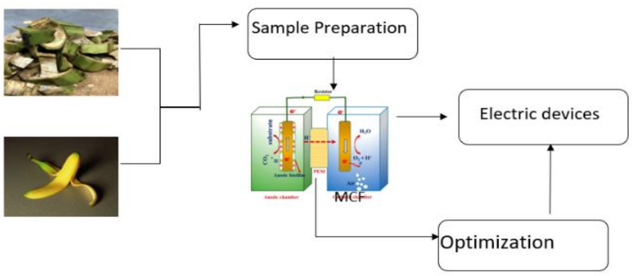


[Fig.2: Cavendish Banana peel (Image Courtesy Segura B.O et al., 2022)]

Electricity is an indispensable aspect of modern life, powering our homes, industries and technologies, and it's difficult to imagine a world without the convenience and comfort that electricity provides [3]. The conventional method of electricity generation, primarily relying on fossil fuels, which have significant environmental and sustainability challenges [2]. As the world faces the urgent need to combat climate change and reduce carbon emissions, there is a growing emphasis on transitioning towards sustainable and renewable energy sources for electricity generation. Rice straw was used as substrate in MFC for power generation [20]. The MFCs used was the H-type which had two chambers (an anaerobic anode chamber and aerated cathode chamber). Results showed that the power density got to 145mW/m^2 with an initial rice straw concentration of 1 g/L and the coulombic efficiencies ranged from 54.3 – 45.3% (corresponding to the initial rice straw concentrations of 0.5 to 1g/L). Also, the stackable MFCs (in series and parallel) produced open circuit voltage of 2.17V and 0.723V respectively. The maximum power for the three stacked MFC (connected in series) was 490mW/m^2 (1.5mA) while in parallel the output was 3-fold (1.5mA) higher than those produced in series [23]. The use of orange peel waste for bioelectricity generation was considered by [21]. A dual chamber laboratory scale MFC was used for the experiment, there were no pretreatment or addition of extra mediators [22]. The results of the maximum voltage generation [24], maximum power density and current density were 0.59 ± 0.02V (at a resistance of 500Ω), 358.8 ± 15.6mW/m^2 and 847 ± 18.4mA/m^2.

III. METHODS AND MATERIALS

Materials used for this Research include plantain peels and cavendish banana peels (fresh), distilled water, a blender, a kitchen oven, digital stopwatch, nose mask, drilling tools, scissor, grinding machine, aluminum mesh, digital electronic laboratory scale, copper wire, salt, unsweetened gelatin, PVC pipe, vulcaseal, spoon, MFC reactor (including anode and cathode compartments, proton exchange membrane, electrodes and connecting wires), substrate containers, and Multimeter. Organic waste substrates used for MFC were banana peel and plantain peel. The peels were locally sourced.



[Fig.3: Schematic Flowchart Process of Bioelectricity Production]

Fig 3. shows the schematic flow chart of bioelectricity generation. It shows the

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process of the research work from sample selection and preparation to the production of bioelectricity and optimization.

A. Sample Selection and Preparation

Healthy Plantain peels (musa paradisiaca) and cavendish banana peels were selected for the experiment. This was done by considering factors such as maturity, size and freshness. The selected samples were washed thoroughly with distilled water to remove impurities. It was soaked in water for 14days, and then grinded with a grinding machine. It was done to soften the material and make it easier to grind into a more homogeneous and fine consistency. Also soaking the peels helps initiate a process called Substrate conditioning. The obtained sludges were left in a sealed container for a further 14 days. During this process Microorganisms present in the peels breaks down the complex compounds into simpler forms such as sugars. The samples were used to determine the amount of substrate added to the anode compartment.

B. Inoculation and Set-Up Procedures

[Fig.4: A Setup of the Dual Chamber MFC Showing the Anode and Cathode Chambers and Proton Exchange Membrane (Salt Bridge)]

In **Fig 4,** The anode compartment was sterilized by rinsing it with a suitable disinfectant solution and then rinsing thoroughly with sterile water. The anode compartment was then inoculated with a mixed culture of electrochemically active microorganisms. The prepared samples were added to the anode compartment as the organic substrate. The cathode compartment were filled with distilled water. The sludges were heated up with an oven within the range of 35-65 degrees Celsius. The external circuit was connected to complete the electrical circuit of the MFC.

C. Monitoring and Data Collection

[Fig.5: Instruments (Digital Scale, Digital Multimeter, Digital Stopwatch) Used for Data Collection]

The multimeter was used to monitor the voltage and current output of the MFC's at regular intervals. The substrate weights were measured using the digital electronic weighing balance. The temperature and heat up time were adjusted using kitchen oven. Digital stopwatch was used to monitor the time.

D. Optimization of Operational Parameters

[Fig.6: Design Expert 13 Home Page]

An experimental study design was done to analyze the optimal capabilities of the MFC. RSM was used to identify the optimum operating status for electricity generation. This includes the application of a set of software aided factor combinations of the experimental runs of a full factorial design called the fractional factorial design. To study the optimal capabilities for current and voltage output using banana sludge, plantain sludge and SYSTEM 1, the central composite design was applied. The central composite design is described as a fractional factorial design which consist of star points (group of axial points) and center point. It is useful in response surface methodology for creating a second order model for specific response variable. Following this definition, fractional factorial design was justified for application in this study to obtain optimal adsorption conditions and interaction of process factors. Experimentally, the process factors also called independent variables; substrate weight (A), time (B), and temperature (c) interacted to produce the response also called the dependent variable (current and voltage output) for the studied MFC's.

Regression models were developed using Analysis of Variance (ANOVA) to predict the current and voltage from three (3) dependent variables which are the study process factors A, B, and C. The significance of the coefficients was assessed through the adjusted sum of squares, adjusted mean of squares, standard Fisher's F-test, and student T-test, all computed from design expert (version 13.0). Also, the significance of the regression coefficients was identified using P-values from the student T-test. For the T-test, the factors that most significantly had an effect on the current and voltage output were identified. The response surface 3D plots for current and voltage outputs were plotted and analyzed.

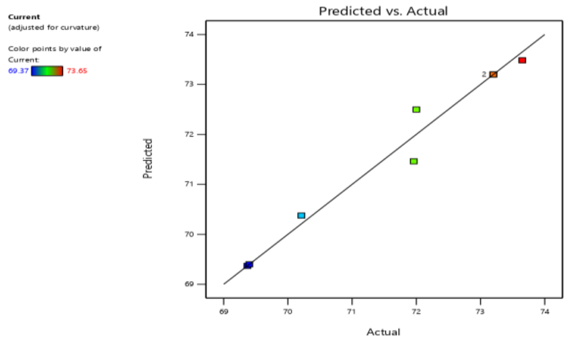
RSM was further employed to identify the optimum operating conditions (the levels at which the variant process factors would yield optimum performance) for the current and voltage output. This was achieved with the aid of the design expert optimizer tool. A two-level three factor fractional factorial design method of optimization was adopted in this study. Model predictions for the best sorption performance were verified with experimental measurements.

IV. RESULTS AND DISCUSSION

Considering Time factor, raw values of the parameters measured for 0.65kg and at Room temperature of 35°C of plantain sludge, banana sludge and SYSTEM 1 sludge

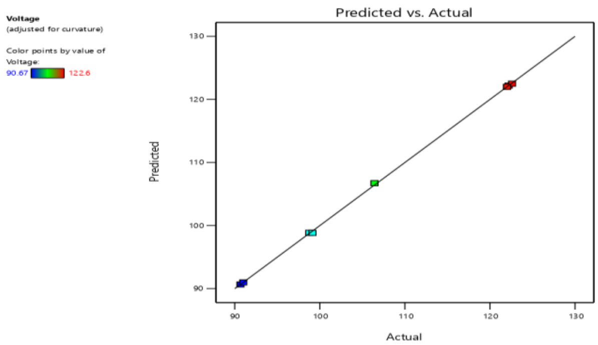
Table 1: Results for MFC Using SYSTEM 1 (Mixed Sludge)

SLUDGE	PLANTAIN		BANANA		SYSTEM 1	
Time (mins)	Response 1: current (μA)	Response 2: Voltage (mA)	Response 1: current (μA)	Response 2: Voltage (mA)	Response 1: current (μA)	Response 2: Voltage (mA)
1	62.4	77.2	72.34	84.2	69.37	90.67
2	63.7	78.4	74.10	86.32	70.21	98.76
3	64.2	79.3	76.36	88.40	71.46	99.14
4	64.9	80.6	79.81	89.36	72.00	106.43
5	65.4	81.9	80.22	90.6	73.14	122.6



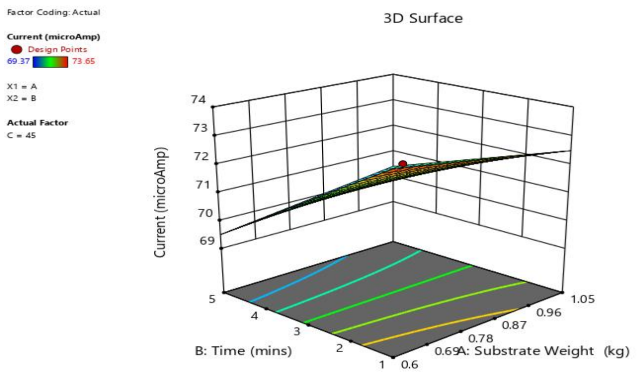
[Fig.7: Predicted vs. Actual Plot of MCF (Current) Using SYSTEM 1 Sludge]

Fig. 7 depicts the Predicted vs. Actual plot of current of the MCF using SYSTEM 1 sludge can be said to be an ideal plot. Few points as observed are within the regression line.



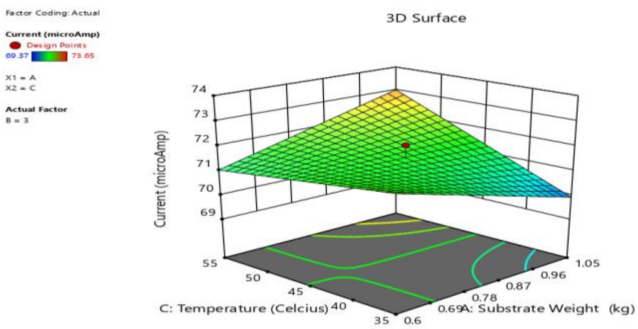
[Fig.8: Predicted vs. Actual Plot of MCF (voltage) using SYSTEM 1 Sludge]

Fig. 8 depicts the predicted plot vs. actual plot of current of the MCF using SYSTEM 1 sludge can be said to be an ideal plot. All point as observed are within the regression line.



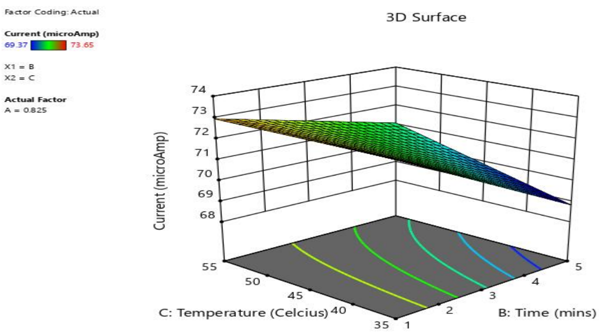
[Fig.9: 3D Plot Interaction for Substrate Weight and Time for Current Production using SYSTEM 1 Sludge]

Figs. 9 depicts the interaction effect between substrate weight and time. It indicated that the current increases with increase in substrate weight value and decrease in time from 0.6 to 1.05kg and from 1 to 5 mins respectively. It was observed that the current output improved when the rapid reaction occurred at high substrate weight and low time.



[Fig.10: 3D Plot Interaction for Substrate Weight and Temperature for Current Production Using SYSTEM 1 Sludge]

Figs. 10 depicts the interaction effect between substrate weight and temperature. It indicated that the current increases with increase in substrate weight value and decrease in temperature from 0.6 to 1.05kg and 55 to 35 degree Celsius respectively. It also shows that there was a decrease in both substrate weight and temperature at about 0.82kg and 46 degrees Celsius



[Fig.11: 3D Plot Interaction for Time and Temperature for Current Production using SYSTEM 1 Sludge]

Figs. 11 depicts the interaction effect between time and temperature. It indicated that the current increases with increase in time value and decrease in temperature from 1 to 5mins and 55 to 35 degrees Celsius respectively. It was observed that the current output improved when the rapid

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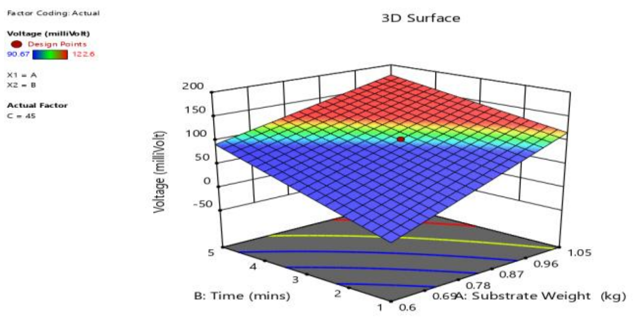
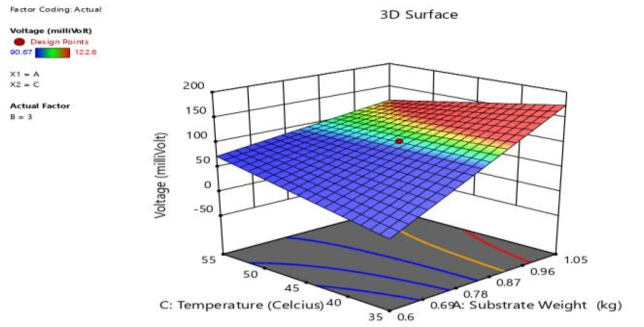
reaction occurred at high time and low temperature. However, the current output will decrease if there is a decrease in time and increase in temperature.



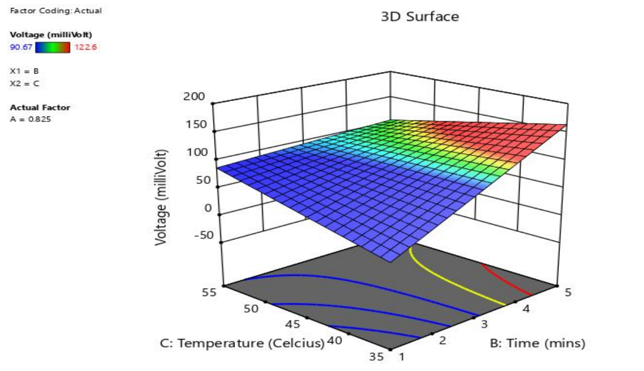
[Fig.12: 3D Plot Interaction for Substrate Weight and time for Voltage Production using SYSTEM 1 Sludge]

Figs. 12 depicts the interaction effect between substrate weight and time. It indicated that the voltage increases with an increase in substrate weight value and increase in time from 0.6 to 1.05kg and 1 to 5 mins respectively. It was observed that the voltage output improved when the rapid reaction occurred at high substrate weight and time. However, the voltage output will decrease if there is a decrease in substrate weight and time.



[Fig.13: 3D Plot Interaction for Substrate Weight and Temperature for Voltage Production using SYSTEM 1 Sludge]

Figs. 13 depicts the interaction effect between substrate weight and temperature. It indicated that the voltage increases with an increase in substrate weight value and decrease in temperature from 0.6 to 1.05kg and 35 to 55 degree Celsius respectively. It was observed that the voltage output improved when the rapid reaction occurred at high substrate weight and low temperature.



[Fig.14: 3D Plot Interaction for Time and Temperature for Voltage Production Using SYSTEM 1 Sludge]

Figs. 14 depicts the interaction effect between time and temperature. It indicated that the voltage increases with increase in time value and decrease temperature from 1 to 5 mins and 35 to 55 degrees Celsius respectively. It also shows that the temperature increased at about 3mins. It was observed that the voltage output improved when the rapid reaction occurred at low time and low temperature. However, the voltage output will decrease if there is an increase in both the time and in temperature.

V. OPTIMIZATION

Numerical method was used for the optimization of the current and voltage output for plantain sludge, banana sludge and SYSTEM 1 sludge. This was done to get the best optimal parameter that will give the best current and voltage outputs.

VI. CONCLUSION

The optimized current and voltage output were investigated using Design expert and RSM statistical tools. Process variables such as substrate weight, time, and temperature, were optimized using RSM tools. The predicted values for current and voltage for the three MFC's were 62.4 µA and 71mV, 72.34 µA and 84.2mV, and, 69.37 µA and 90.67mV for Plantain, Banana and SYSTEM 1 Sludges respectively. While the actual values for current and voltage for the three MFC's were 68.4 µA and 81.9mV, 80.223 µA and 90.6mV, and, 73.65 µA and 90.67mV for Plantain, Banana and SYSTEM 1 Sludges respectively. The results show the values of the optimization for the currents and voltage of the three MFC's to be 67.7605 µA and 92.6117mV, 107.893 µA and 109.447mV, and, 73.4518 µA and 199.454mV using plantain sludge, banana sludge and SYSTEM 1 sludge. Comparing the current and voltage output from the results, the MFC with the banana sludge produced the highest amount of current while SYSTEM 1 produced the highest amount of voltage. However, the three MFC's studied has demonstrated its optimal effectiveness and potential application for the electricity generation.

VII. RECOMMENDATION

Based on the study, plantain Sludge, banana sludge and SYSTEM 1 sludge exhibited a good optimized current and voltage output. Hence it is recommended that these optimized MFC's be inculcated in power generation due to its eco-friendliness, biodegradability, cost effectiveness, and availability. Other agricultural waste can be considered as substrate for further study, as this study was limited to only two substrates. Determining the optimized conditions for the current and voltage output using the variance and other statistical tools can be considered for further study, as this study was limited to only 3 factorial variants, and RSM design method of optimization.

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DECLARATION STATEMENT

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- **Authors Contributions:** The authorship of this article is **contributed** equally to all participating individuals.

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