

Influence of Electrode Material on the Electrical Discharge Plasma Generation and its Application in Seed Germination Enhancement

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Abstract

This study investigates the influence of electrode materials, specially copper and aluminium, on dielectric barrier discharge (DBD) plasma generation and its application in enhancing seed germination rates of mung bean (*Vigna radiata*). Furthermore, understanding the interaction between electrode materials and electrical parameters is important to optimize the plasma treatment process, thus providing a potentially effective and sustainable method to increase agricultural productivity. Acrylic was used as the dielectric material in these air pressure experiments, which were powered by 240 V, 50Hz AC power source connected to a neon transformer. The impact of aluminium and copper electrodes electrical characteristics on the intensity and initiation of plasma were investigated. According to the results, seeds treated with plasma germination rates were much greater than those of untreated seeds. Copper electrodes proved to be more effective because of their higher electrical conductivity. Copper initiated plasma at 2.2 kV and intensified at 2.92 kV, whereas aluminium required 2.24 kV for initiation and reached maximum intensity at 3.0 kV. According to the study's findings, copper electrodes produce plasma more steadily and effectively, which makes them more suited for use in agricultural applications that aim to improve seed germination.

1. Introduction

Seed germination is a crucial stage in the life cycle of plants, marking the transition from seed to seedling. The efficiency of this process significantly influences crop yield and overall agricultural productivity. In recent years, non-thermal plasma technology has emerged as a promising tool for enhancing seed germination without the adverse effects associated with traditional treatments. This project focuses on the influence of electrode material on the electrical discharge plasma generation and its application in seed germination enhancement.

Du Moncel [1] published a description of his experiments in 1855, demonstrating that two conducting plates divided by two glass plates can produce an electrical discharge. Published research on the application of plasma technology shows that plasma treatment has a favourable impact on plant development and seed germination. Without appreciably changing the percentage of germination, Volin et al. [2] were able to produce either delayed or accelerated germination in a number of distinct agricultural species. For instance, germination was sped up in soybean and corn seeds but delayed in pea, radish, soybean, corn and bean seeds when specific

gas and plasma conditions were used. Furthermore, as Jiang et al. [3] showed for wheat and oats, the alteration in the seeds' wettability, at least partly because of the oxidation of their surface during plasma treatment, can result in quicker germination and greater yield. Because plasma therapy interacts complexly with organic components and live cells, it can have a wide range of impacts on seed morphology. Because plasma therapy interacts complexly with organic components and live cells, it can have a wide range of impacts on seed morphology. According to reports by Khamsen et al. and Basaran and Akhan [4], the seeds' surface characteristics were altered and they were sterilised as an additional effect of the plasma treatment. Alexandra Waskow et al., [5] in his review presents the parameters to consider during plasma treatment of seeds. The aim of his paper is to identify and analyze each seed-plasma treatment parameter that is relevant for reproducing experiments. This includes the design of the plasma device, the analysis of the seeds, and reporting of the results. It is divided into four main parts, namely Plasma device; Seed preparation; Seed-plasma treatment; and Seed Post treatment. Some research, such as the following, show that seeds were pre-selected based on their colour, size, weight, and form before receiving plasma treatment. A. Los, et. Al [6] said that only healthy seeds devoid of obvious flaws or indications of infection were chosen for the investigations, or seedlings that revealed moulds were repurposed. However, according to C. LoPorto et. al. [7], only whole seeds devoid of obvious flaws were chosen. Filatova et al [8], recommended that a 5 min plasma treatment was found to be the most effective. However, D. Dobrin et al [9], 15 min yielded the most substantial increase in length in; and finally, Y. Li et al [10] suggested a 7-minute treatment resulted with an increase in germination potential, rate, index, and vigour index. Each had a corresponding power of 9, 2.7, and 1.5 W, in that order.

The generation and application of dielectric barrier discharge (DBD) plasma in agricultural practices present a complex challenge that encompasses both material science and electrical engineering aspects. One critical issue is determining the optimal electrode material for efficient plasma generation. This study specifically investigates the influence of copper and aluminum electrodes on the initiation and intensity of DBD plasma. The experiments are conducted at atmospheric pressure with acrylic serving as the dielectric material. Furthermore, the study explores the practical application of the generated plasma in enhancing seed germination rates of mung bean (*Vigna radiata*). Understanding the interplay between electrode material and electrical parameters is essential for optimizing the plasma treatment process, thereby providing a potentially effective and sustainable method to improve agricultural productivity. This research aims to fill the knowledge gap in electrode material selection for DBD plasma generation and its practical implications for seed treatment in agriculture.

The main aim of this project is to propose a prototype of a electrical discharge plasma system for seed germination enhancement by a dielectric barrier discharge (DBD) plasma system by using 50 Hz 240V and Neon Transformer power supply. The specific objectives include compare the efficiency of copper and aluminium electrodes in generating dielectric barrier discharge (DBD) plasma. Lastly, these objective seek to evaluate the effectiveness of DBD plasma generated by different electrode materials in enhancing Mung Bean seed germination.

2. Methodology

2.1 The development of plasma generator

To ensure that the entire project proceeds smoothly and successfully in order to meet the goal and objectives, the flowchart presented in Fig. 1 illustrates the project planning ultimate objective.

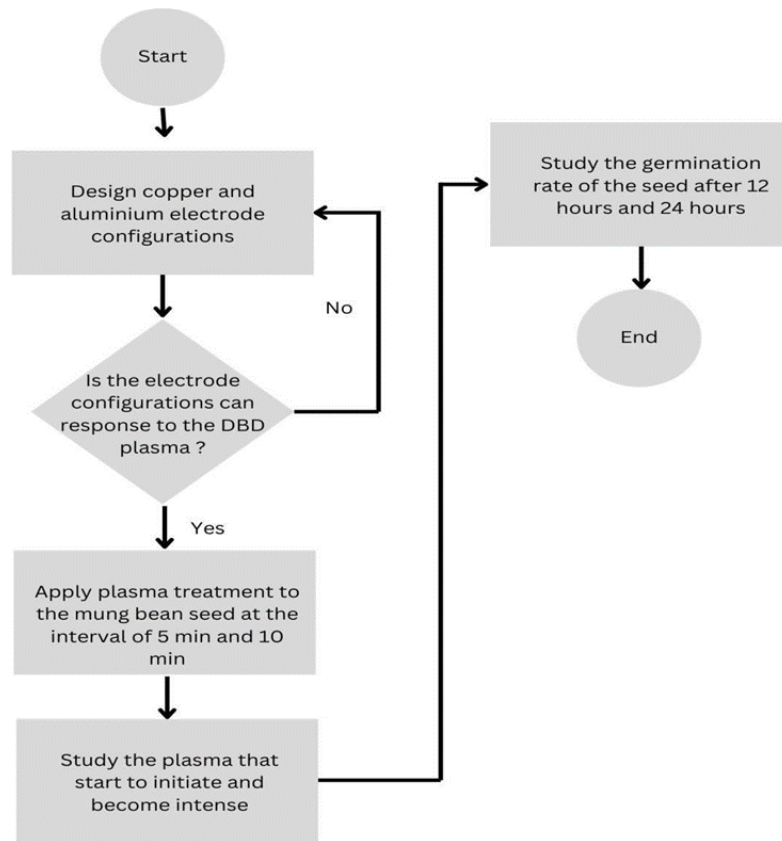


Fig. 1 Flowchart for overall project

2.2 Material

The choice of materials is crucial in a plasma project aimed at providing plasma treatment for seed germination to guarantee process efficacy and safety. Copper and aluminium electrodes are used because of their high electrical conductivity, robustness, and corrosion resistance. In order to ensure a steady and homogeneous plasma discharge, a dielectric barrier typically composed of glass, ceramic, or quartz is necessary to avoid direct contact between electrodes. The aluminium, borosilicate glass, or stainless steel plasma reactor chamber offers a regulated environment resistant to chemical reactions and extreme temperatures. Electrical components in the power supply convert energy to the necessary frequency and voltage to sustain the plasma. Aluminium, stainless steel mesh, and junction box are used to create safety enclosures that shield users from UV rays and high voltage. Each component is chosen according to its special qualities in order to produce a safe, effective, and dependable plasma generating procedure that improves seed germination.

2.3 Design of electrode configurations

When designing electrode configurations to generate plasma, there are several important factors to consider when using copper and aluminum tape. Because copper tape and aluminum tape are flexible and conductive, they are often used as electrode materials. Typically, the arrangement is asymmetrical and has electrodes spaced apart by a dielectric material. This configuration allows the production of plasma with certain properties. Controlling the homogeneity and efficiency of the generated plasma largely depends on the location and shape of the electrodes. The thrust generation and efficiency of the plasma actuator is affected by the dimensions and configuration of the electrodes and the space between them. Furthermore, plasma performance and characteristics are affected by electrical parameters such as frequency, rise time and voltage waveform. So, in this project it will use digitated design. Fig. 2 shows the design by AutoCAD for copper electrode configuration (a) and aluminium electrode configuration (b). Fig. 3 shows a cross sectional view of dielectric barrier discharge configuration for this project.

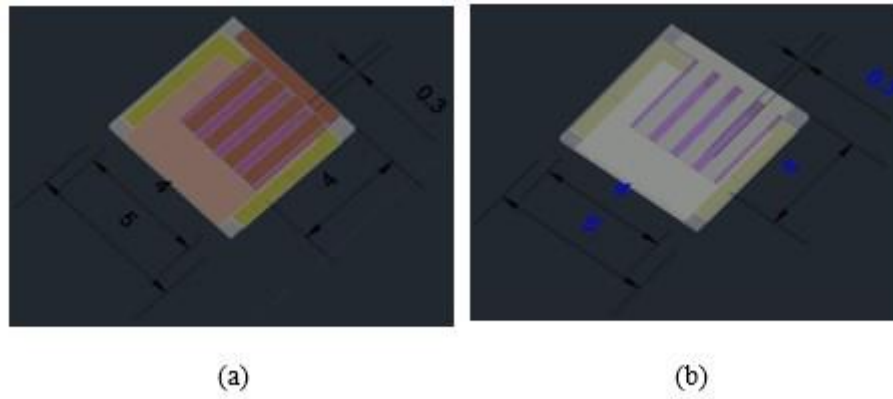


Fig. 2 Dimension design of electrode configuration (a) copper electrode (b) aluminium electrode

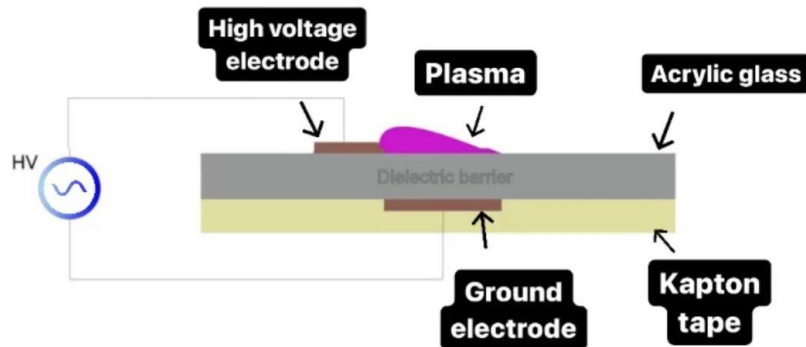


Fig. 3 Cross sectional view of dielectric barrier discharge configuration

2.4 Schematic diagram

The schematic diagram of experimental setup for DBD plasma treatment is shown in Fig 4. The setup consists of a surface DBD plasma chamber, a high voltage probe, an oscilloscope and a high voltage (HV) transformer. A 240V, 50Hz power source is connected to the HV transformer to increase the voltage required to create the plasma in the surface DBD chamber. During experiments, the surface DBD plasma chamber is grounded to provide stability and safety. High voltage probes are strategically placed to measure the voltage across the DBD plasma chamber and to prevent damage to the oscilloscope. Additionally, it reduces the input voltage to a safe and measurable level using a precision voltage divider circuit in the probe body.

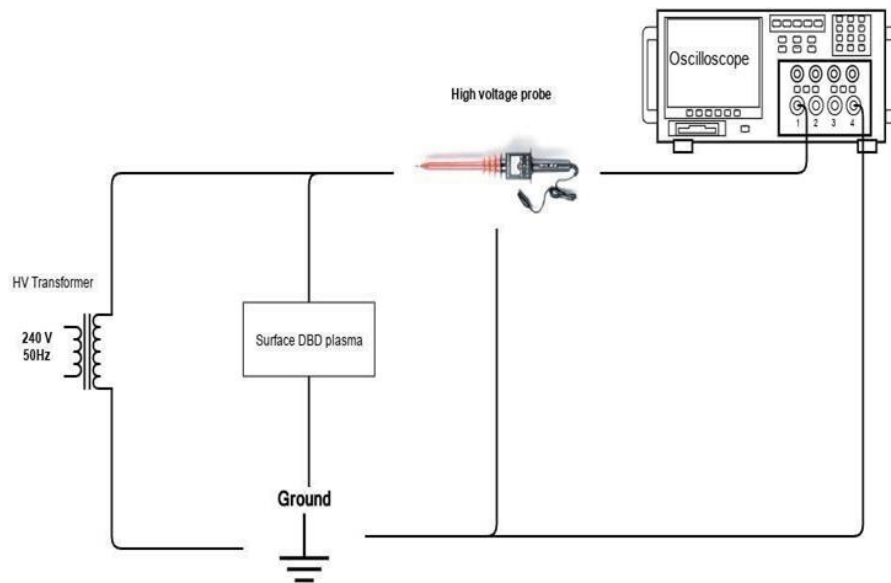


Fig. 4 Schematic diagram of experimental setup for DBD plasma treatment

2.5 Experimental Setup

This circuit diagram illustrates a setup designed to generate plasma for seed treatment applications. The setup includes four main components which are high voltage power supply, variable voltage regulator, transformer and plasma generation chamber. The complete of experimental setup for DBD plasma treatment is shown in Fig. 5.

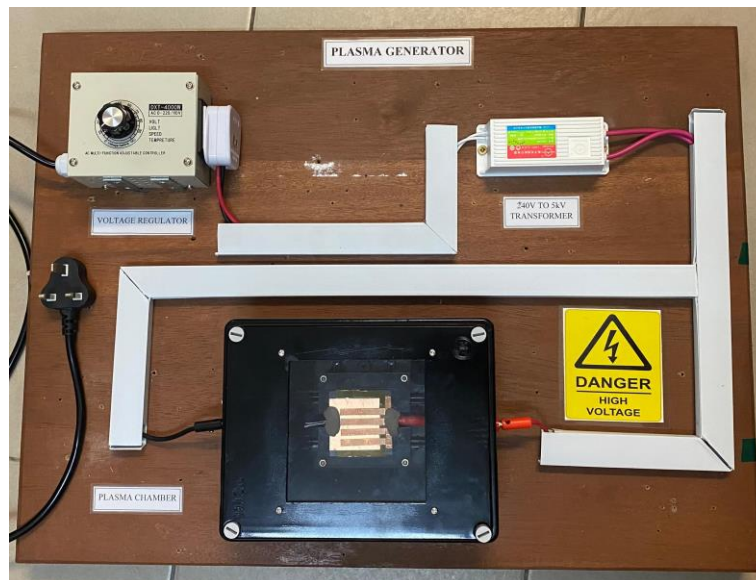


Fig. 5 Complete experimental setup for generate plasma treatment

This circuit diagram illustrates a setup designed to generate plasma for seed treatment applications. The setup includes four main components which are high voltage power supply, voltage regulator, transformer and plasma generation chamber. The high-voltage power supply, placed on the left, has a main power switch and a control dial to adjust the output voltage. This controlled voltage is then directed to a high voltage generator (central device), where it is amplified or transformed to the level required for plasma generation. The internal components of the generator ensure that the voltage is converted and stabilized effectively. From the generator, a high-voltage cable transmits the voltage to the plasma generation chamber (bottom device). Inside this chamber, electrodes made of materials such as copper or aluminum tape create an electric field across a dielectric barrier, such as acrylic glass. When a high voltage is applied, the gas in the chamber ionizes, producing a plasma. The transparent window of the chamber allows visual monitoring of the plasma treatment process, ensuring that it is uniform and effective.

3. Result and discussion

This section discusses the development of the copper and aluminium tape for DBD plasma. The analysis will begin with the formation of electrical discharge plasma. The comparison of the effect of copper and aluminium electrodes on the formation of DBD plasma will be presented. Next, the application of surface DBD plasma on seed germination also presented. Lastly, the comparisons were made depends on the copper and aluminium tape on seed germination.

3.1 Formation of DBD plasma by copper and aluminium electrode configurations

Using an electrode configuration of copper and aluminium, a dielectric barrier discharge (DBD) plasma is formed by applying 50Hz frequency voltage in a methodical manner. Electrodes made of copper and aluminium tapes are utilised because of their excellent electrical conductivity. The electrode is positioned on the other side of the acrylic glass dielectric barrier. The gap containing the gas to be ionised creates an electric field when a 50Hz frequency alternating voltage is placed across the electrodes. The formation of DBD plasma produced by copper electrodes and aluminium electrode are examined in this experiment and it was can investigate variations in plasma stability, colour, and intensity by altering the applied voltage. Gaining an understanding of these characteristics is essential to improving the application efficacy of plasma generation and process optimisation. The attached picture as show in Fig. 6 and Fig. 7 illustrates the basic concepts and operational dynamics of DBD plasma with copper and aluminium electrodes.

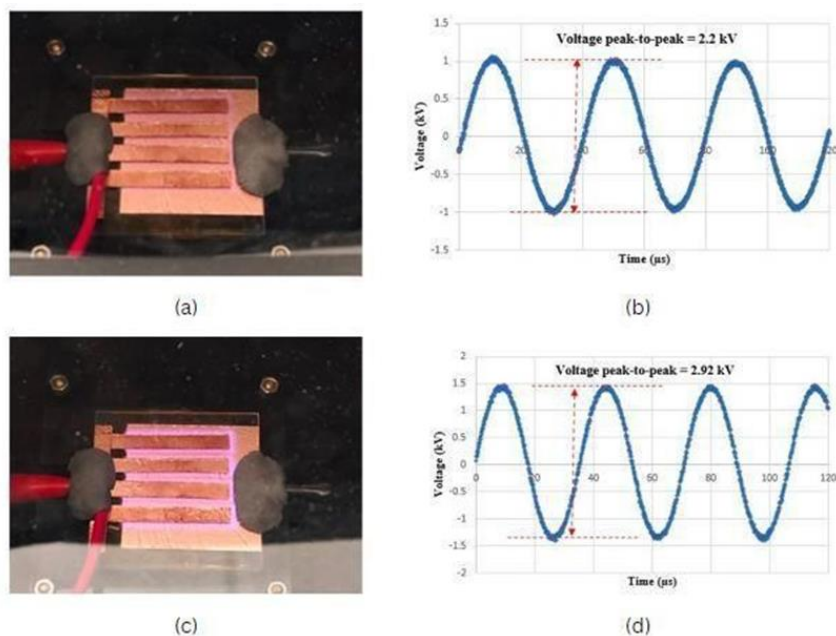


Fig 6 Characteristics of plasma generated by the copper electrodes surface DBD. (a) Image of plasma discharge in 2.2 kV, (b) sinusoidal voltage waveform vs time in 2.2 kV, (c) image of plasma discharge in 2.92 kV and (d) sinusoidal voltage waveform vs time in 2.92 kV.

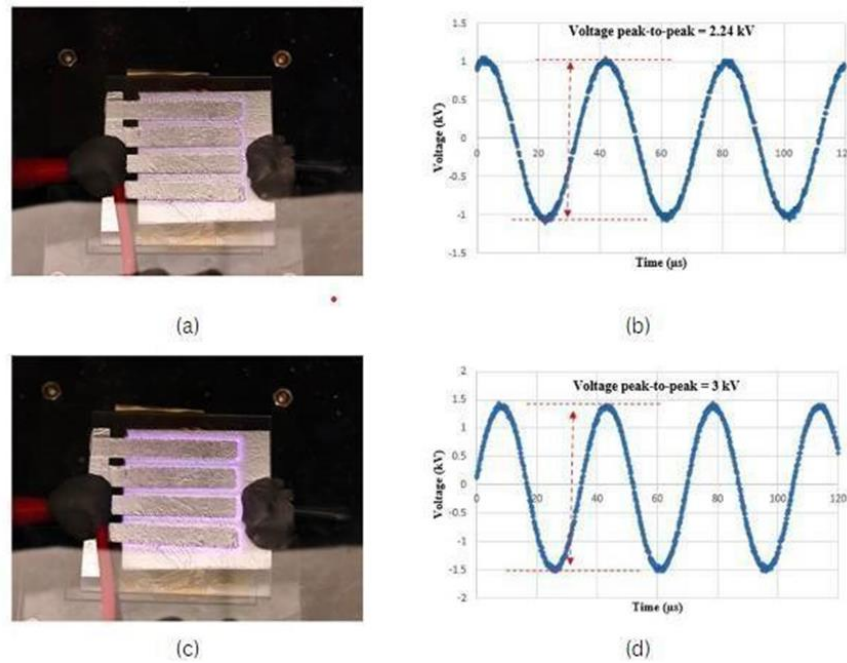


Fig 7 Characteristics of plasma generated by the aluminium electrodes surface DBD. (a) Image of plasma discharge in 2.24 kV, (b) sinusoidal voltage waveform vs time in 2.24 kV, (c) image of plasma discharge in 3 kV and (d) sinusoidal voltage waveform vs time in 3 kV.

To assess copper and aluminium electrodes' efficacy in plasma generation, the formation of Dielectric Barrier Discharge (DBD) plasma was studied. The stability, plasma colour, intensity, and ignition voltage of the plasma varied according to the electrode material. Aluminium electrodes needed a little higher voltage of 2.24 kV to begin plasma generation, whereas copper electrodes performed do at 2.2 kV. When the voltage was raised, the light purple plasma created by both electrode materials turned into a dark purple colour. An increase in energy and density of plasma is indicated by this colour shift. On the other hand, aluminium electrodes peaked at 3 kV, while copper electrodes attained their maximum intensity at 2.94 kV. Copper electrodes work better to produce DBD plasma than aluminium electrodes do. Copper electrodes is a superior option because of its exceptional electrical and thermal properties, which allow it to ignite plasma at a lower voltage, sustain higher plasma intensity at slightly lower maximum voltages, and maintain stable plasma. Aluminium electrodes work well, although they need a little bit more voltage and might not be as stable over time. Therefore, copper electrodes are recommended for applications demanding efficient and stable plasma generation.

3.3 Application of surface DBD plasma treatment on seed germination

Seed germination is a physiological process that begins with the seeds' water absorption (imbibition) and ends with the root emerging. To study the effect of the plasma energy dosage on seed germination using aluminium (label as A) and copper (label as C) with different electrode configuration, different plasma treatment times (5 and 10 minutes) are also monitored. The seed germination rate is monitored after 12 h and 24 h. The germination rate, defined as the number of germinated seeds per the total number of seeds. Seed germination were significantly enhanced after plasma treatment after 12 hrs and 24 hrs of sowing on cotton under the same conditions except for the non- treated seeds as shown in Fig. 8 and Fig. 9.



Fig 8 After 12 h of plasma treatment with copper (C) and aluminium (A) at different electrode configuration



Fig 9 After 24 h of plasma treatment with copper (C) and aluminium (A) at different electrode configuration

3.4 Seed germination treatment by copper and aluminium electrode DBD plasma

For plasma treatment with copper 2.2 kV in 5 minutes, the results show 16.67 % increased from 66.66% after 12 h to 83.33% after 24 h. For plasma treatment with copper in 2.2 kV in 10 minutes also show equal result (increase 16.67 %) from 83.33% after 12 h to 100% after 24 h. After 24 h, all seeds were germinated under this condition as shown in Fig. 10.

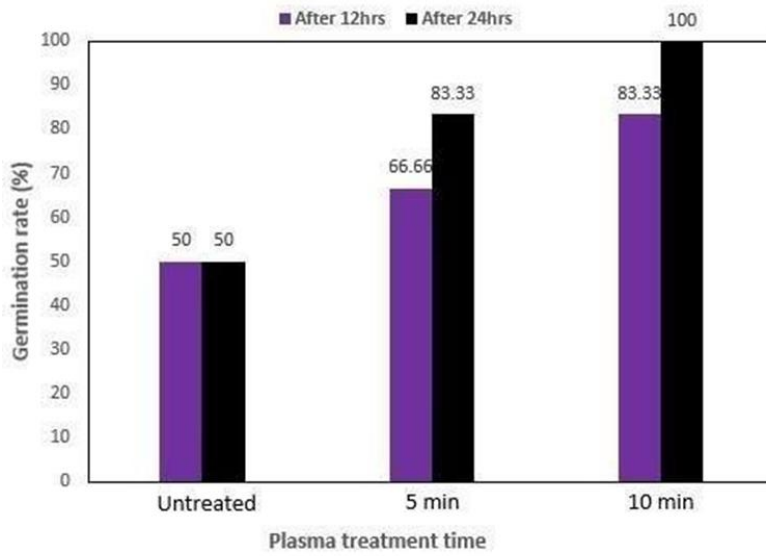


Fig 10 Seed germination after 12 h and 24 h of plasma treatment with copper using 2.2 kV

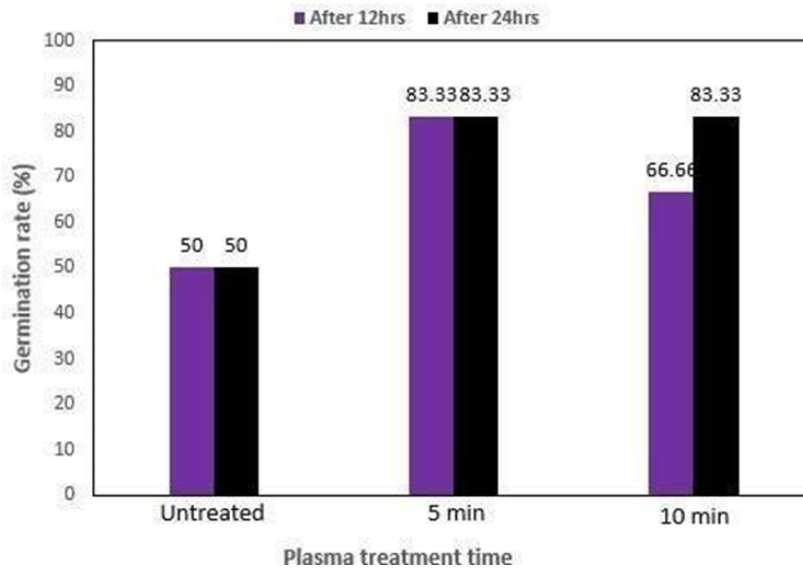


Fig 11 Seed germination rate after 12 h and 24 h of plasma treatment with copper using 2.92 kV

While for plasma treatment with copper 2.92 kV in 5 minutes, the results show no improvement in the seed germination rate. It shows the same results (83.33%) after 12 h and 24 h. For plasma treatment with copper 2.92 kV in 10 minutes, the result shows increased from 66.66% after 12 h to 83.33% in 24 h. For the non-treated seeds, the germination rate is only 50 % for both 12 h and 24 h of monitoring at the same condition as shown in Fig. 11.

For plasma treatment with aluminium 2.24 kV in 5 minutes, the result shows 16.67% increased from 83.33% after 12 h to 100% after 24 h. After 24 h, all seeds were germinated under this condition. For plasma treatment with aluminium 2.24 kV in 10 minutes also show equal result (increase 16.67 %) from 50% after 12 h to 66.66 % after 24h as shown in Fig. 12.

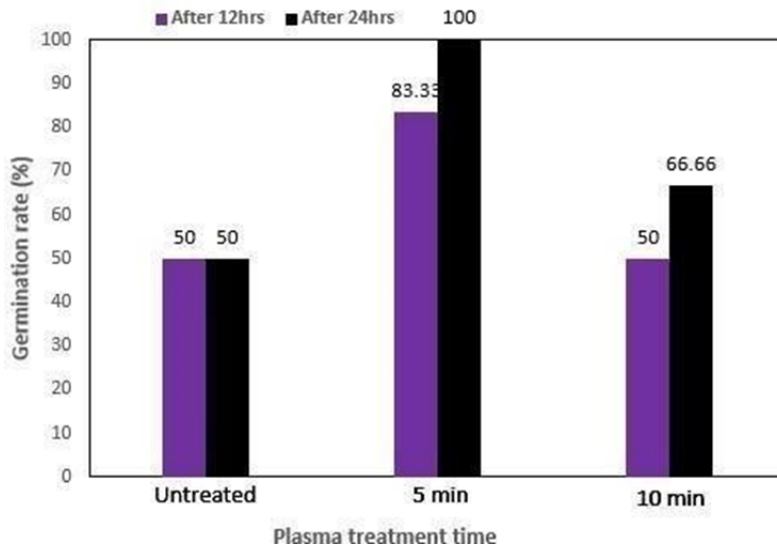


Fig 12 Seed germination rate after 12 h and 24 h of plasma treatment with aluminium using 2.24 kV

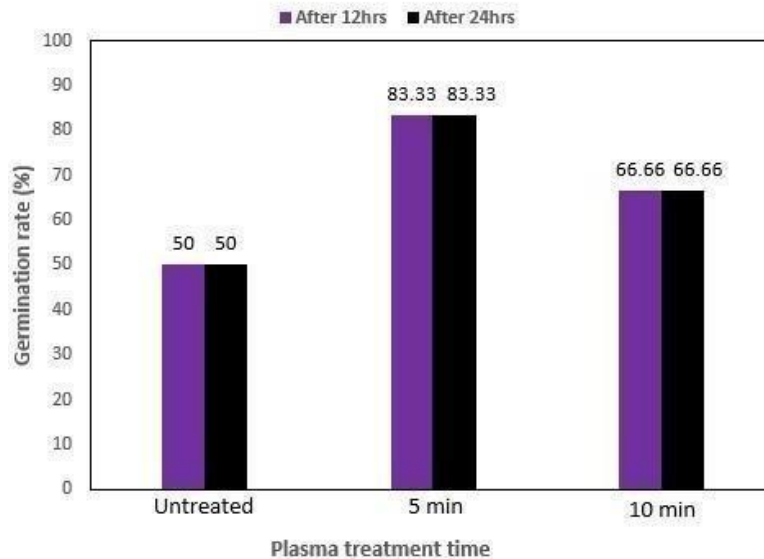


Fig 13 Seed germination rate after 12 h and 24 h of plasma treatment with aluminium using 3 kV

While for plasma treatment with aluminium 3 kV in 5 minutes, the results show no improvement in the seed germination rate. It shows the same results (83.33%) after 12 h and 24 h. For plasma treatment with aluminium 3 kV in 10 minutes, the result also shows the same results (66.66%) after 12 h and 24 h. For the non-treated seeds, the germination rate is only 50 % for both 12 h and 24 h of monitoring at the same condition as shown in Fig. 13.

For the untreated beans, they showed similar germination rate (50%) after 12 h and 24 h. It shows that the progress of the untreated seeds is slower when compare to those with plasma treatment as reported in various study. When compare to the time of exposure to plasma treatment, seeds germination was significantly enhanced in 5 minutes compare to 10 minutes. The observation also agreed with a recent report from Le et. al (2022) [20] and Cui, D. et al (2022) [21] which indicated that short-time plasma treatment promoted seed germination, while long-time plasma treatment could have inhibitory effects. While in 10 minutes exposure with plasma treatment using 2.92 kV, the results show copper is much better compare to aluminium by 16.67% increases in germination rate after 12 h and 24 h of observation. The study shows that plasma treatment with copper is more effective than aluminium for germination of seeds for both 2.2 kV and 2.92 kV.

4. Conclusion

In conclusion, the development of a dielectric barrier discharge (DBD) plasma system using a 50 Hz, 240 V power supply and a Neon Transformer successfully achieved the objective of creating a stable and effective plasma generation setup. Precise control and measurement of the electrical properties of the plasma were made possible by the system design, which includes a grounded surface DBD plasma chamber for safety and a high-voltage probe coupled to an oscilloscope for real-time monitoring. This preparation showed that could effectively create and preserve DBD plasma, which makes a workable technique for uses like enhancing seed germination, where plasma treatment may significantly improve the rates of seed germination. Next, to compare the efficiency of copper and aluminum electrodes in producing dielectric barrier discharge plasma (DBD) was also successfully showing that copper electrodes are more effective than aluminum electrodes in producing dielectric barrier discharge plasma (DBD) to increase seed germination. Additionally, the copper electrode showed a higher proliferation rate than aluminum, particularly when the plasma reached a maximum voltage of 2.92 kV. The evaluation of DBD plasma generated by different electrode materials in enhancing Mung bean are successful observed. Following 12 and 24 hours of observation, there was a notable rise in germination rates with plasma treatment, especially with copper electrodes, which produced a 16.67% higher germination rate than untreated seeds. This finding is consistent with other studies that suggested longer plasma treatment could prevent germination. These highlight the significance of maximising the positive effects of plasma treatment on seed germination by optimising electrode material and treatment duration.

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