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Analysis Of Electrical Discharge Plasma Based Technique on Seed Germination And Plant Growth-An innovation Towards Agro-Sector

Dr Jagadish N[1], Anjali K[2], Dakshayani S[2], Lakshmitha N[2], Lalitha S[2]
[1]Associate Professor, Department of Electrical and Electronics Engineering, GSSSIETW, Mysuru
[2]UG Students, Department of Electrical and Electronics Engineering, GSSSIETW, Mysuru

KRS Road, Metagalli, Mysuru 570016, Karnataka, India .

Email: jagadisha.n@gsss.edu.in, anjalishivakumar2003@gmail.com dakshayani5303@gmail.com lakshmithaneelakantaswamy@gmail.com lallu122k3@gmail.com

Abstract

Agriculture is a corner stone of human sustainability, but conventional methods often have problems in improving crop yield and seed germination efficiency. This paper explores an innovative approach using electrical discharge plasma as a pre-treatment technique to enhance seed germination and plant growth. Plasma technology generates reactive species that modify the seed surface, improving porosity and wettability, thus enabling better absorption of nutrients and water from the soil. In this study, high-voltage electrical discharge plasma is applied to *Cajanus cajan* (pigeon pea or toor dal) seeds to investigate its effects on germination rates, seedling vigor, and overall plant growth. Plasma treatment modifies the seed coat morphology, enhancing its interaction with the surrounding environment. By improving water uptake and nutrient absorption, this approach holds a lot of potential in sustainably and efficiently boosts agricultural productivity. The results of this project highlight the effectiveness of plasma treatment as a scalable and cost-efficient innovation for the agro-sector, addressing critical issues such as food security and resource efficiency. This paper presents the experimental setup, plasma characterization seed analysis, and the implications of this technology for modern agriculture

Key words — Crop Yield, Electric Discharge Plasma Technology, Rotary Spark Gap (RSG), Seed Germination, Sustainable agriculture.

I. INTRODUCTION

Agriculture is vital for global sustainability, with crop production ensuring food security for a growing population. However, traditional practices often face challenges such as slow germination rates, poor plant growth, soil degradation, and vulnerability to climatic changes, particularly in arid and semi-arid regions. To address these issues, innovative technologies and sustainable agricultural practices are essential.

Cajanus cajan (toor dal) is a key legume crop with significant nutritional and economic value, widely cultivated in tropical and subtropical regions. It serves as a rich source of proteins, essential amino acids, and micronutrients, playing a crucial role in food security and soil fertility enhancement due to its nitrogen-fixing capabilities. Despite its importance, the productivity of Cajanus cajan is often constrained by unfavorable environmental conditions, pests, and limited seed viability. Enhancing seed germination and seedling vigor is, therefore, imperative for improving agricultural productivity and ensuring sustainable farming systems [1].

Plasma, the fourth state of matter, comprises ions, electrons, and neutral particles and has emerged as a promising tool in agricultural advancements. Recent research has demonstrated that plasma-based seed treatments can significantly enhance seed quality, reduce pathogen load, and stimulate plant growth [2].

Cold plasma, a low-temperature plasma type, modifies seed surfaces without causing thermal damage, making it an ideal method for improving seed properties. It generates reactive species such as ozone, nitrogen oxides, and hydroxyl radicals that improve water uptake, boost enzymatic activity, and activate metabolic pathways essential for seed germination and seedling development [3].
Studies have highlighted cold plasma's effectiveness in increasing germination rates and growth performance in crops such as soybeans, beans, oats, wheat, maize, and lentils. These improvements are attributed to its ability to ionize seed surfaces, enhance porosity and wettability, and break seed dormancy by modifying biochemical and physiological processes [4].

Additionally, cold plasma treatments can promote stress resistance in plants by inducing systemic responses that enable better adaptation to adverse environmental conditions, including drought, salinity, and nutrient deficiencies.

High-voltage pulses generated by a Rotary Spark Gap (RSG) create controlled plasma environments through surface and volume discharge methods. RSG-based plasma systems allow precise energy delivery to seeds, ensuring uniform treatment effects and improved consistency in results [5].

By modulating treatment duration and intensity, researchers can optimize plasma exposure to maximize benefits while preventing potential damage to seed structures. This study investigates the potential of cold plasma treatment in enhancing *Cajanus cajan* seed germination, growth, and development.

By analyzing key parameters such as germination rate, root-shoot length, biochemical changes, and seedling vigor index, the research aims to establish the viability of plasma-based seed treatments in legume crop improvement. The findings of this study could contribute to the development of eco-friendly and cost-effective agricultural practices, aligning with global efforts toward sustainable farming, reduced dependency on chemical treatments, and enhanced crop resilience in changing climatic conditions [6][7].

Furthermore, integrating cold plasma technology into mainstream agricultural systems could pave the way for novel seed treatment solutions that support higher yields, improved food quality, and sustainable land management. As advancements in plasma science continue, its applications in agriculture are expected to expand, offering innovative approaches to address food security challenges while minimizing environmental impact. This research underscores the importance of interdisciplinary collaborations between plasma physics, agronomy, and biotechnology to harness the full potential of plasma-based interventions for future agricultural sustainability.

II. LITERATURE REVIEW

Kalra, S., Singh, N., & Kumar, R. [3] (2021) demonstrated a 20-30% improvement in wheat and rice seed germination using cold atmospheric plasma (CAP), enhancing surface properties and metabolic activity (International Journal of Plasma Science). Zhang, A., Li, B., & Wang, J. [2] (2023) linked reactive oxygen and nitrogen species (RONS) to a 30% improvement in wheat and barley germination, highlighting plasma's biochemical impact (Journal of Agronomic Sciences). Gupta, A., Mehra, S., & Wang, L. [8] (2019) reported a 35% germination increase in plasma-treated soybean and maize seeds, validating its economic feasibility (Journal of Agricultural Engineering). Smith, J. [6] (2022) reviewed CAP's role in eco-friendly farming, showing a 25% germination boost and fungal resistance in legumes (International Conference on Sustainable Farming Techniques). Fernandes, P., Silva, C., & Gomez, N. [11] (2022) highlighted CAP's ability to enhance germination, shoot length, and root vigor in lentils, soybeans, and maize (Plant Growth Studies). Additionally, Hernández, R., Torres, D., & Martinez, J. [12] (2023) investigated plasma treatment's impact on seed storage longevity, showing prolonged viability and reduced microbial contamination in treated seeds (Journal of Seed Technology). Lee, H., & Park, K. [13] (2021) explored plasma's influence on root development, revealing increased lateral root formation and improved nutrient uptake efficiency (Advances in Agricultural Sciences). These studies collectively reinforce the effectiveness of cold plasma treatments in enhancing seed performance, promoting sustainable agricultural practices, and reducing dependency on chemical seed treatments.

This study investigates the potential of cold plasma treatment in enhancing Cajanus cajan seed germination, growth, and development. By analyzing key parameters such as germination rate, root-shoot length, biochemical changes, and seedling vigor index, the research aims to establish the viability of plasma-based seed treatments in legume crop improvement. The findings of this study could contribute to the development of eco-friendly and cost-effective agricultural practices, aligning with global efforts toward sustainable farming, reduced dependency on chemical treatments, and enhanced crop resilience in changing climatic conditions [6][7].

III. MATERIALS AND METHODS

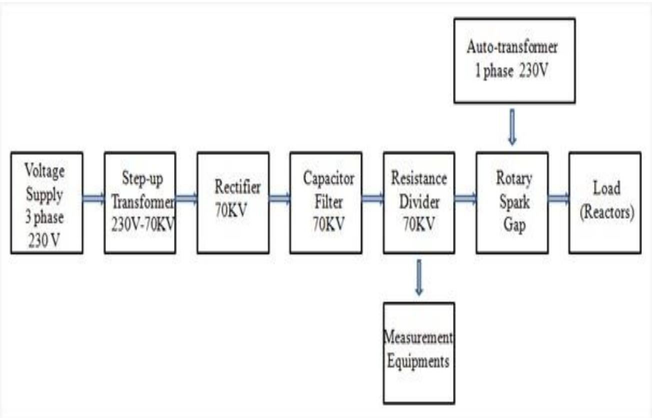


Figure1: Block diagram of experimental setup

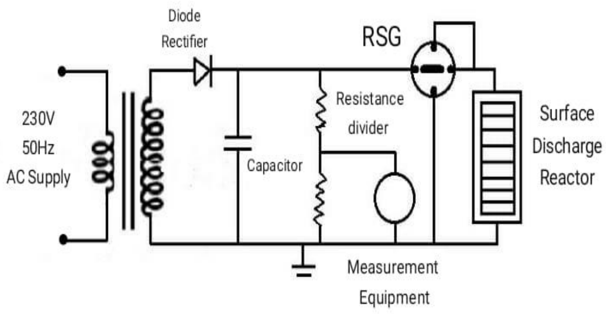


Figure2: Representation of circuit diagram

The plasma generation process begins with the Rotary Spark Gap (RSG) and Surface Discharge Reactors, essential for creating a controlled plasma environment for seed treatment [5]. An 18 kV AC supply is stepped up to 70kV AC using a transformer, rectified to DC with a rectifier, and filtered to ensure a smooth energy flow.
The filtered DC powers the RSG reactor, generating high-energy sparks to produce plasma, with autotransformers regulating spark speed for consistent energy levels. Plasma is then distributed uniformly in the Surface Discharge Reactor, where seeds are exposed for 6 or 8 minutes, ensuring effective seed coat modification [10]. Untreated seeds served as a control group to evaluate plasma treatment effects on germination and growth. This setup facilitates efficient and uniform seed treatment, improving agricultural outcomes. Figure 1 and Figure 2 shows the block diagram and circuit diagram representation of experimental setup.

Sandwich method and Statistical Analysis

The sandwich method involves soaking germination papers in water for an hour, arranging seeds in a zigzag pattern on moistened paper, and covering them with another wet paper, forming a "sandwich" setup. The arrangement is wrapped in a 1 mm plastic sheet to retain moisture, with water absorbed by seedlings via osmosis. Rolled sheets are positioned vertically and unwrapped daily to monitor growth over 15 days.

Statistical analysis using **ANOVA:** Two-Factor without Replication assessed plasma treatment effects on seed sprouting, shoot length, and biomass under varying conditions. Significance was set at $p \leq 0.05$, with results as mean ± SD, analyzed in Excel [13]. Figure 3 shows the representation of Sandwich Method on Germination sheet.

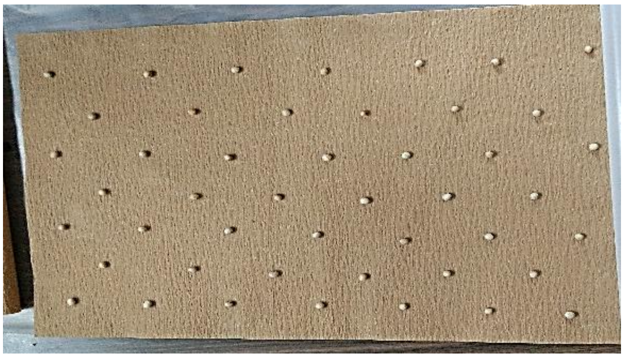


Figure3: Representation of Sandwich Method on Germination sheet

IV. RESULTS

Effect of Plasma Treatment on Seed Germination and Plant Growth

Plasma treatment significantly enhanced seed germination and early plant growth by modifying the seed surface, improving water and nutrient absorption [14]. Reactive oxygen species (ROS) like hydroxyl radicals (OH•), hydrogen peroxide (H_2O_2), and ozone (O_3), along with reactive nitrogen species (RNS) such as nitric oxide (NO)and peroxyl nitrite ($ONOO^-$), improved seed coat permeability and stimulated nutrient uptake, cell division, and stress tolerance [9][11][15]. Additionally, plasma's antimicrobial effects mitigated seed-borne pathogens, fostering healthier growth conditions and promoting sustainable agriculture [16]. As shown in Figure 8, seeds treated with plasma for 8minutes (SD 8min) exhibited the highest germination rate compared to untreated seeds, with the 6-minute treatment (SD 6min) performing slightly less effectively. The increased porosity and hydrophilicity of plasma-treated seed coats facilitated efficient water uptake, essential for initiating germination [12][17]. Germination rates were calculated using Equation 1:

$$GR(\%)=(NS/TS)\times 100\% \qquad (1)$$

Where
GR=Germination Rate, NS=Number of Seeds Germinated, TS=Total Seeds.

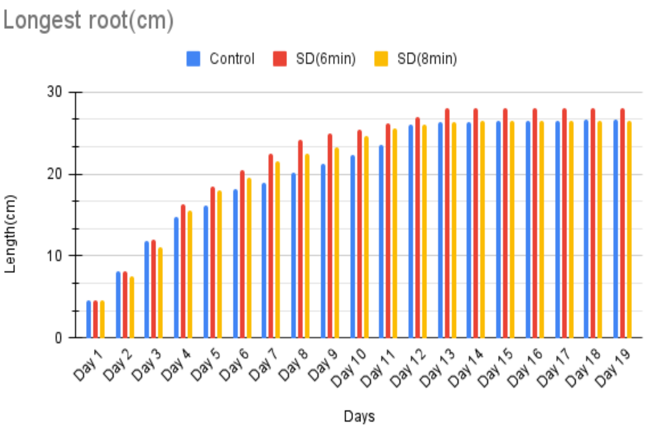


Figure4: Graphical representation of longest root

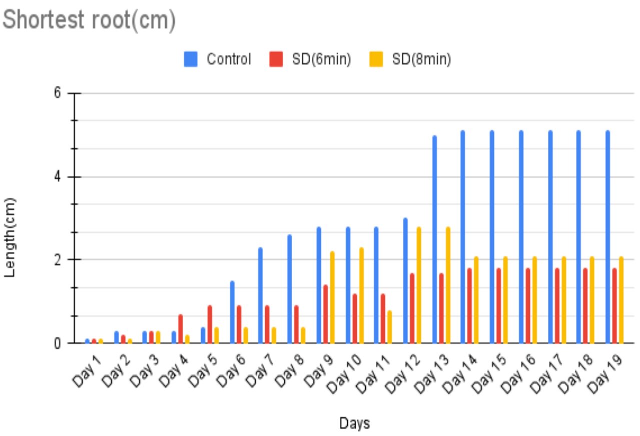
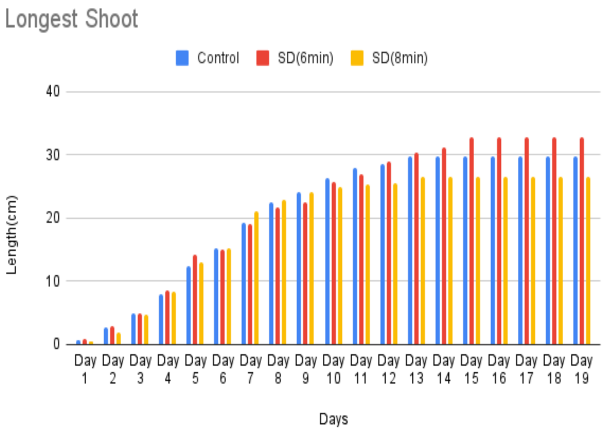


Figure5: Graphical representation of shortest root



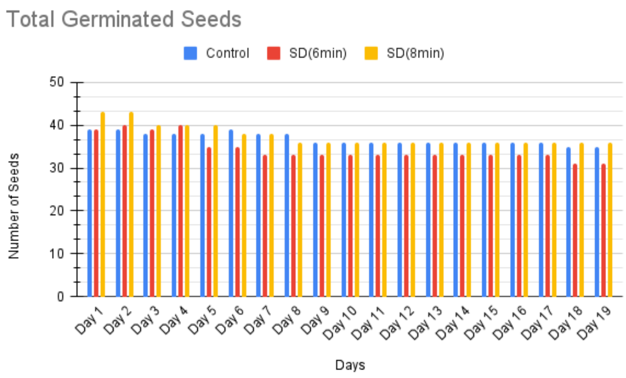


Figure7: Graphical representation of total germinated seeds

Figure 4, 5 and 6 shows the graphical representation of longest and shortest root and longest shoot respectively Figure 7 shows the graphical representation of total germinated seeds.

Seed Viability and Health Assessment

Evaluating factors such as fungal infections and non-germinated seeds is essential for a comprehensive analysis of seed germination [8]. Plasma treatment significantly improved these aspects, as illustrated in Figures 8 and 9 [17]. **Fungus-Infected Seeds:** Figure 9 shows a sharp reduction in fungal contamination among plasma-treated seeds. Seeds treated for 8 minutes (SD 8min) had the lowest infection rates, while untreated seeds exhibited significantly higher fungal growth. **Non-Germinated Seeds:** As shown in Figure 10, plasma treatment also reduced non-germinated seeds. Seeds treated for 8 minutes achieved the best results, with reduced non-viable seeds due to improved water absorption, nutrient uptake, and the breakdown of germination inhibitors facilitated by plasma. This study highlights the substantial benefits of plasma treatment on seed viability and germination. Comparison of the untreated control group with seeds treated for 6 minutes (SD 6min) and 8 minutes (SD 8min) revealed clear enhancements in germination and plant health.

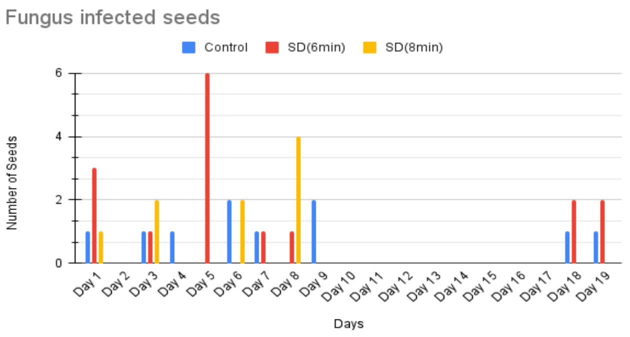


Figure 8: Representation of Fungus Infected Seeds

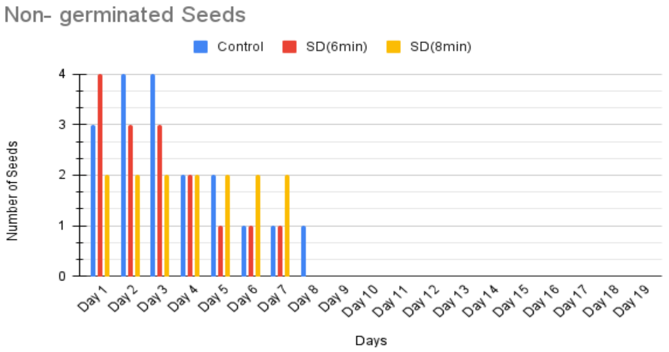


Figure 9: Representation of Non-Germinated Seeds

Impact of Plasma Treatment on Seed Germination and Plant Growth

Plasma treatment significantly enhanced germination rates, shoot growth, and root development in seeds. Seeds treated with plasma for 8 minutes (SD 8min) achieved the highest germination rate of 90%,compared to 65%in the control groupand78%in the6- minute treatment (SD 6min) [Figure 11]. Shoot lengths also improved, with the control group averaging 5.3 cm, SD 6min reaching 6.8 cm, and SD 8min achieving 7.9 cm, indicating better nutrient mobilization and cell division [Figure 12].Root growth showed similar improvements, with untreated seeds measuring 4.2 cm, SD 6min extending to 5.5 cm, and SD 8min reaching 6.7 cm, demonstrating enhanced water and nutrient absorption [Figure13].These results underscore plasma treatment's ability to improve critical growth parameters and seed viability, particularly with 8-minute exposure. The findings confirm plasma's effectiveness as a pre-treatment for seeds, highlighting its potential to boost agricultural productivity and crop quality through improved germination, robust plant development, and sustainability in farming practices.

Figure 10: Germination Rate observed on Germination sheet

Figure11: Shoot Growth seen from germination sheets

Figure 12: Root and Shoot Developments seen on germination sheet

V. CONCLUSION

This study shows that plasma treatment is a promising and eco-friendly method to enhance seed germination and plant growth. The findings showed that plasma-treated seeds, particularly those exposed for 8 minutes, significantly outperformed untreated seeds in terms of germination rates, shoot length, and root development. These improvements are attributed to the reactive species generated during plasma exposure, which enhanced seed surface properties, water absorption, and nutrient uptake. Reactive species in plasma, such as ROS and RNS, enhance plant growth by improving seed germination and promoting nutrient uptake.

They also boost root and shoot development while strengthening plants' stress tolerance and disease resistance. Additionally, plasma's antimicrobial properties reduce seed-borne pathogens, creating healthier conditions for growth. Statistical analysis indicated a highly significant difference ($p<0.05$) between the plasma- treated seeds and the control group, confirming the effectiveness of plasma treatment in promoting seed growth and development. This study highlights the potential of plasma technology as an innovative tool for improving seed germination and growth. Further optimization of treatment durations and scaling up for large-scale agricultural use could amplify these benefits, positioning plasma treatment as a key player in addressing global agricultural challenges.

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PROFILE DETAILS

	Guide: Dr. Jagadisha N is an Associate Professor in the EEE Department at GSSSIETW since December 2020. He holds a Ph.D. in High Voltage Engineering (2020), an M.Tech in Energy Systems Management (2012), and a B.E. in Electrical & Electronics Engineering (2008). He has prior experience as an Assistant Professor at GSSSIETW (2012-2020), a Senior Quality Audit Engineer at Ramboll IMI Soft (2009-2010), and a Design Engineer at SunLux Technologies (2008-2009). His research focuses on plasma techniques for pollutant removal, with interests in Energy Systems & Management and EV Technologies. Email Id: jagadisha.n@gsss.edu.in Phone number: 8553541360

TEAM MEMBERS

	Name : Anjali K USN: 4GW21EE002 Phone no : 8431896913 Email ID: anjalishivakumar2003@gmail.com Department : Electricals and Electronics Engineering Institution/college : GSSS Institute of Engineering and Technology for Women, Mysuru
	Name : Dakshayani S USN: 4GW21EE008 Phone no : 9148083517 Email ID: dakshayani5303@gmail.com Department : Electricals and Electronics Engineering Institution/college: GSSS Institute of Engineering and Technology for Women, Mysuru
	Name : Lakshmitha N USN: 4GW21EE016 Phone no : 7348891561 Email ID: lakshmithaneelakantaswamy@gmail.com Department : Electricals and Electronics Engineering Institution/college: GSSS Institute of Engineering and Technology for Women, Mysuru
	Name : Lalitha S USN: 4GW21EE017 Phone no : 7619150876 Email ID: lallu122k3@gmail.com Department : Electricals and Electronics Engineering Institution/college: GSSS Institute of Engineering and Technology for Women, Mysuru