Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 44 No. 10
October 2023

The mobility of Nitrogen Ions in the Atmospheric Corona Plasma and Its Possibility to Accelerate the Growth of Mung Bean Plants

Sumariyah Sumariyah[1,2*], Fauziah Rahmi [1], Rianti Warto Utami [1], Asep Yoyo Wardaya[1,2], K. Sofyan Firdausi [1,2], Fajar Arianto [1,2], Zaenul Muhlisin [1,2], Sulistiyani Hayu Pratiwi[2], Heri Sugiarto[3], and Muhammad Nur [1,2*]

[1]Departement of Physics, Diponegoro University, Semarang, 50275, Indonesia.
[2]Center for Plasma Research (CPR), Diponegoro University, Semarang, 50275, Indonesia.
[3]Mlatiharjo Farmer Groups, Demak, 59581, Indonesia.
*Corresponding author: (E-mail: sumariyah@lecturer.undip.ac.id)

Abstract

The cold atmospheric plasma (CAP) using corona discharge technology with a multipoint-to-plate electrode configuration has been used to accelerate the growth of mung beans. Mung bean seed growth was carried out by analyzing and measuring the growth rate of sprouts, root length, leaf width, stem height, and plant dry weight every five days for 15 days. This growth was compared to seeds (control) that did not receive CAP treatment from corona discharge. The results showed that growth effectiveness increased with increasing irradiation time. Total nitrogen content was measured in green bean seeds irradiated. We suspect that the increase in green bean growth is caused by an increase in nitrogen in the seeds by the intrusion of nitrogen ions when the seeds are irradiated by CAP species from positive corona discharges.

Keywords: Cold atmospheric plasma, mung bean, corona discharge, multipoint-to-plate electrode, ions mobility, growth acceleration

1. Introduction

At the present time, plasma technology has been widely applied in the fields of agriculture, particularly in the treatment of food crops, seeds and soil [1,2,3,4]. Cold atmospheric plasma (CAP) can provide many advantages in applications of agriculture, such as: can be operated at relatively low temperatures and processing times are relatively short, and does not cause damage to the seed, crop, food, operator human, and environmental [1]. Reactive species such as charged species (ions, electrons), reactive neutral species, the electric field, and the ultraviolet radiation are generated in the plasma discharge [5]. These factors led to a change in the density of reactive oxygen species (ROS), reactive nitrogen species (RNS), pH, redox potential, electrical conductivity, and so on, and affect seed germination, plant growth, and the quality of agricultural products [6]. Plasma corona is one type of cold plasma in a plasma classification based on temperature. Cold plasma which uniform and well controlled at atmospheric pressure is now able to be produced, thus creating the opportunity to apply plasma in a safe and controlled for food and biological surfaces. Several experiments have shown the effects of plasma for seeds germination and plants growth. Hayasi et al. investigated the effect of plasma on growth of radish sprout (*Rhapanus sativus var. longipinnatus*). This shown enhanced germination, with up to 1.6 times longer root and stem development in plants after implant period of 3 day [7]. In another study, using a scalable Dielectric Barrier Discharge (DBD) device to treatment the seeds of *Raphanus sativus* (L.) (radish sprout) has been observed. Koga et. al. used system that contains 20 electrodes having 1 mm outer diameter and 60 mm length covered with a ceramic tube of 2 mm outer diameter. The seeds were irradiated by plasma for 3 minutes in room temperature. These results indicated that plasma irradiation can accelerate growth of radish sprout. Plasma irradiation not only enhances stem growth but also improves crop yield. It led to increases of 56% in the total weight of harvested seeds, 12% in the average weight of one seed, and 39% in seed number [8].

Mung bean (*Vigna radiata*) is a legume from Asia, now widely cultivated throughout Asia, Australia, New Zealand, and Africa. Inside of mung bean contains source of vitamins, minerals, and protein with an ideal acid of essential amino [9]. The high availability of nutrients in mung bean lead people to cultivate it as food such as porridge, flour, and so on. Moreover, some society believe that consuming mung bean can afford to overcome anemia [10]. In Indonesia, the majority of mung bean production are in Java, particularly Central Java and East Java, and South Sulawesi [11]. The production of mung bean in Indonesia is inadequate to fulfill the necessity of public. Low production of mung bean due to some factors such lack of availability of quality seeds, social and economic barriers, lack of interest of farmers in the cultivation of mung bean plants and methods of cultivation which are less precise.

The mainly gases in the earth's atmosphere is nitrogen, nearly 78 % of the total, and nitrogen has a prominent role in plant growth and development, as a protein compound-forming material required plant during the growth period. In plants, nitrogen can be obtained through electrical discharges such as lightning in the form of oxides of nitrogen. In this case, plasma technology serves to supply the needs of nitrogen for plants directly from the air through the infiltration of ion N^+. One of the means to generate plasma is through electrical discharge. Plasma which formed in the electrical discharge is known as corona glow discharge plasma. In addition, infiltration of nitrogen ions into a material will modify the microstructure of the material, so that the physical properties of the material and chemical will also change. were calculated, which then will be associated to the changes in the growth of the mung bean seed samples. Irradiations to the mung bean samples were conducted with some variation of irradiation times. Irradiation was carried out under atmospheric pressure and free air was used as the source of the ionized gas. Irradiation factors that allegedly give changes to the growth of mung bean were evaluated, either in seed samples irradiated and on the parameters irradiation through the ion mobility value. After irradiation, irradiated mung beans then planted up to 15 days. Total nitrogen contents in the seeds of mung bean were to be associated with the growth parameter of the mung bean plants are: stem length, root length, leaf width, and the dry mass, affect seed germination, plant growth, and the quality of agricultural products.

In this research, we used cold atmospheric plasma (CAP) to accelerate the growth of mung bean. CAP was generated by using corona plasma reactor with multi-point plane configuration. The acceleration of growth has been analyzed by measuring the growth rate of sprouts, root length, leaf width, stem height, and plant dry weight. The characterizations of current versus voltage values were conducted both without and with the samples, and the values of the mobility of ions.

2. Experimental

2.1. Experimental Facilities

The fig. 1 shows the experimental set-up for plasma corona system reactor along with power supply and the instrumentation for voltage and current measurement. The equipment comprise of two electrodes, point electrode was made by 64 stainless needles with 2 cm in length, each needle is separated further 1 cm, while plate electrode was made by aluminum (15.6 cm x 15.8 cm). Both electrodes were fixed on statif. The variety of distance between electrodes was from 1 cm to 4 cm, characteristic current against voltage was carried out with presence and absence of sample. Mung bean seeds were put on plate electrode. During all experiments, we have measured the value of voltage and current discharge at each distance with sample and without sample.

For characteristics I-V without sample, the voltage was applied in a range from 0 kV to 8 kV, while I-V with sample from 0 kV to 8.40 kV. Characteristics I-V were carried out for each distance until the reactor system is igniting corona discharge. Corona discharge emerged through point electrodes and it was marked with sounds and purple light.

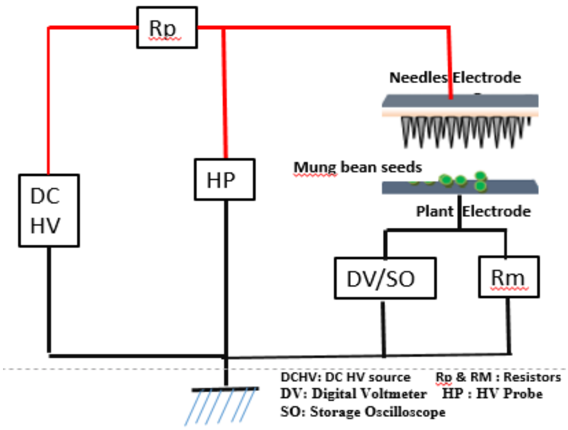

Fig 1: Experimental set-up of corona glow discharge plasma reactor

2.2 Instrumentation for I-V Plasma Characterization

We used DC high-voltage (0 kV – 10 kV) as a source of potential, while the output voltage waveform across the two electrodes of the corona glow discharge plasma was measured using a high voltage probe (DC max voltage 40 kV, EC 1010, EnG1010 Taiwan), respectively, and an oscilloscope (GOS-653 50 MHz). The output current discharge was measured by an analog multimeter (Sanwa YX361TR, China).

2.3 Biological Procedure and Sample Preparation

We picked mung bean (*Vigna radiata*) variety of vima-1 as sample in this research. Mung bean seeds were separated into 6 groups, 5 group were irradiated by plasma corona and one group as control. The 5 groups irradiated plasma were distinguished based on time irradiation for 5 minutes, 15 minutes, 30 minutes, 45 minutes, and 60 minutes. After all seeds were irradiated, we put samples into water for 8 hours before seeds were cultivated into soil. Some seeds were observed for 24 hours concerning the growth rate of sprout. Sprout length was monitored every 4-hours. Other seeds were cultivated into black soil. Analysis of root length, stem height, leaf width, and weight of dry mass were measured as parameter of growth on the 5th day, 10th day, and 15th day during cultivation. Furthermore, charge carrier mobility was measured to determine the nitrogen content before and after irradiated.

2.4 I-V Characteristics and Charge Mobility

The determination of the value of average charge carrier mobility can be made based on current characteristics as a function of voltage using equation Sigmond[11]. The value of this unipolar ion mobility can be calculated using equation (1). But for the case of the multi-point electrode, this equation can be necessary modified a factor of the number of electrode points, which is considered N. In addition, the dielectric constant values also should be corrected. We have to use constant of dielectric samples between two electrodes, these samples can be considered as a dielectric material. Thus, the above equation becomes:

$$I_s = \frac{2\mu\varepsilon_t N}{d}(V^2) \quad (1)$$

With μ is mobility of charge carrier, N is number of needles, d is distance between two electrodes, V is applied voltage and electric discharge current strength is symbolized by Is. A linear curve $\sqrt{I_s}$ as a function of V can be made, in order to obtain the gradient of the curve linearity. From the gradient value may be determined and average mobility of the charge carriers in the corona discharge. The effective of dielectric constant between two electrodes should be calculated. These materials include air and rice as a sample.

3. Results and discussion

3.1. I-V Characteristics and Charge Mobility

Figure 2. shows characteristics curve of current versus voltage with and without samples. Figure. 3. Characteristic curve of current vs voltage in corona reactor in the presence of mung bean sample

The aim of the characterization was to obtain the value of current and voltage while corona glow discharges are ignited through reactor. Results indicated that increasing current is proportional with voltage increases for all electrode distances cases. This case is convenient with Sigmond's theory [12]. Furthermore, the minimum voltage to ignite corona discharge in reactor with sample was at 1.6 kV, while the maximum voltage was at 9.2 kV. Besides, in case of similar voltage value, the current values with presence of samples are higher than current values with absence of samples. It occurs due to mung bean seed is dielectrics in which it will be polarized in electric field, and causing the seeds become charged. Polarization effects to the seeds make the upper surface of seed closed to point electrodes become negatively charged and the lower ones become positively charged. If distance between electrodes is closer, the current value will be higher. The dielectric constant value for mung bean is 3.23 [13].

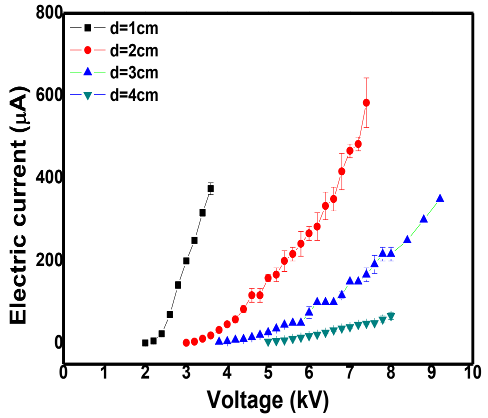

Fig 2: Characteristic curve of current vs voltage in corona reactor in the absence of mung bean sample, and (b) presence of mung bean sample

In this experiment, the current and voltage were used to treatments of mung bean seeds at 3.6 kV and 20.5 μA respectively. At this condition, corona glow discharge plasma marked by the sound of the sizzle on the tips of the electrode needles. Corona discharge plasma process accompanied by glowing colored purple between electrodes.

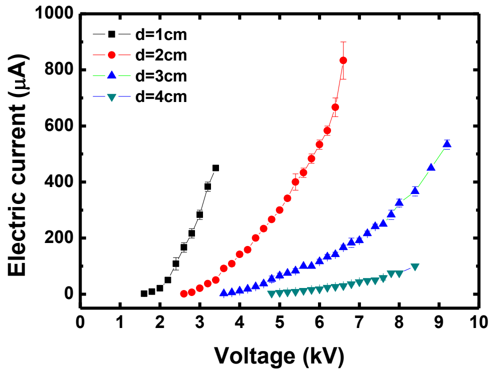

Fig 3: Characteristic curve of current vs voltage in corona reactor in the presence of mung bean sample

Figure 4 shows the graph of square root of current as function of voltage at a distance of 2 cm in reactor system. At this distance, the values of tgα1 are always greatest rather than tgα2 due to the dielectric values are becoming increasingly more with rise of load which causes an increase of current because of seed polarized by high electric field

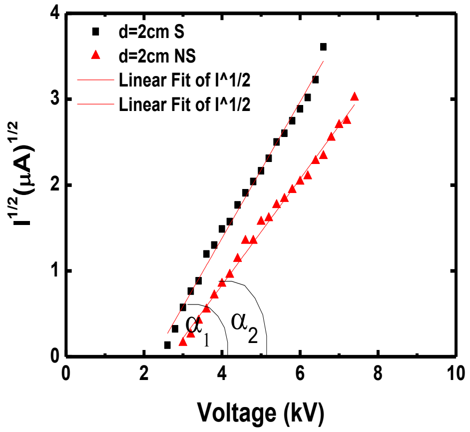

Fig 4: Curve of mobility against voltage at 2 cm gap between electrodes

Figure. 5. Shows the threshold voltage is needed in order to ignite corona glow discharge plasma at 1 cm to 4 cm. it is clear that the value of early voltage with sample are more likely higher rather than the value of early voltage without sample

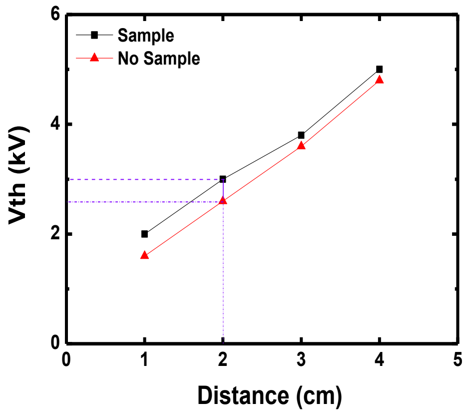

Fig 5: Threshold voltage for several distance of electrodes with samples and without samples

Ionization occurs by glow corona discharge will produce N^+ ion. These ions will flow toward the anode and cause ion currents called the unipolar saturation current. This current is greatly influenced by the mobility of the charge carriers. Calculation of the charge carrier mobility is obtained from the Sigmond's equation of charge carriers rate of positive ion or negative ion [14]. Fig. 6 shows that the values of mobility decrease against distance between electrodes. This condition occurs due to reducing of electric field between the electrodes, so that the movement of the electrons collision with free air becomes slow.

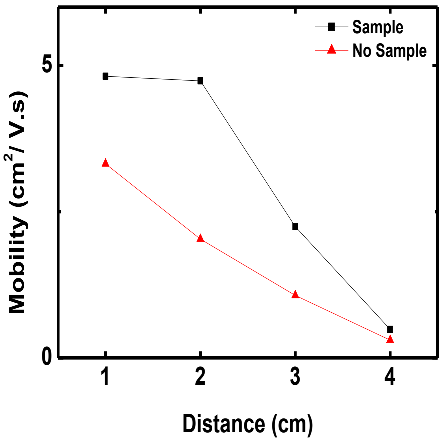

Fig 6: Curve of mobilities of charge carriers against distance in corona reactor in the absence and presence of sample

The results of mobility with and without sample are extremely different. The value of mobility without sample is lower than mobility using a sample. This difference is influenced by the speed of the ions to infiltrate the mung bean seed is faster than without sample. Figure 6 shows the comparative value of mobility with sample will always be higher than without the sample. The value of this ratio is only between grades 1 and 3 with an average ratio of 1.87 ± 0.21. The addition of distance provides the smaller in mobility ratio value. It is influenced by the growing distance between electrodes resulting smaller electric field is getting smaller. The smaller the electric field causes the free charge carrier particles to be difficult to move.

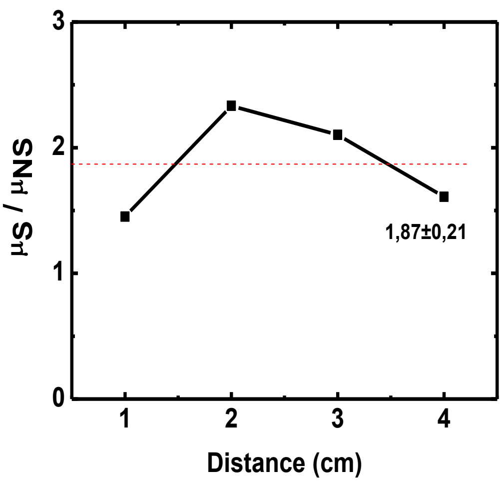

Fig 7: Ratio curve of mobility in corona reactor in the absence and presence of sample.

3.2. Growth Acceleration of Mung Bean Plants

Mung Bean Plants are started by grain-shaped seeds. Cold Atmospheric Plasma (CAP), has shown many advantages in the agricultural sector. The advantage of applying this sector is that it allows the removal of specifications and contaminants from the seed surface [20]. CAP can increase the shelf life of plant life seeds, increase germination and resistance to abiotic stress. Figure. 8 shows the growth speed of the mung bean shoot for 24 hours. Result indicated that time treatment for 5 minutes on mung bean seed tend to faster instead of the others.

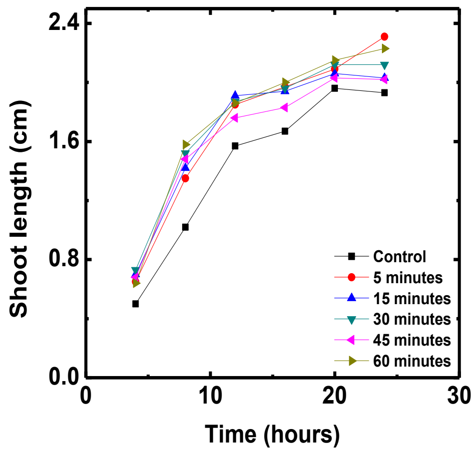

Fig 8: Growth speed of mung bean shoot for 24 hours

The average of mung bean shoot length for 5 minutes irradiation was at 2.31 cm, followed by 60 minutes and 30 minutes at 2.23 cm and 2.12 cm respectively. For time treatment of 45 minutes and 15 minutes the average of shoot length were similar at 2.03 cm. According to the data, the average shoots length of irradiated samples was higher compared with non-irradiated mung bean seeds.

As can be seen from the figure 9, 10, 11, 12, the growth of mung bean plants irradiated by corona glow discharge plasma were faster compared with non-irradiated mung bean plants. Moreover, the treatment-time obviously influence the growth of mung bean plants was more effective between 15 minutes and 30 minutes. By contrast, distribution of plasma for long-term period to the seeds could be less optimal due to nitrogen excess. Some reports have shown that longer exposure results a detrimental effects on seeds [15], [16]. Corona glow discharge plasma is enable to produce nitrogen ions from air [14], and these ions were inserted into seeds of mung bean. Consequently, the proportion of nitrogen was experiencing the escalation of speed and could accelerate mung bean growth as well. According to the amount, nitrogen in air is more dominant of nearly 78 % of total, so that ion nitrogen which are formed in plasma condition has a huge probability to be diffused into mung bean plants and influence the growth and development of plants than any other ions. Therefore, the increasing of the nitrogen proportion in seeds of plants could accelerate the plant growth significantly. On the other hand, higher exposure times of CAP generated in a nitrogen atmosphere significantly inhibited succinate dehydrogenase activity [21].

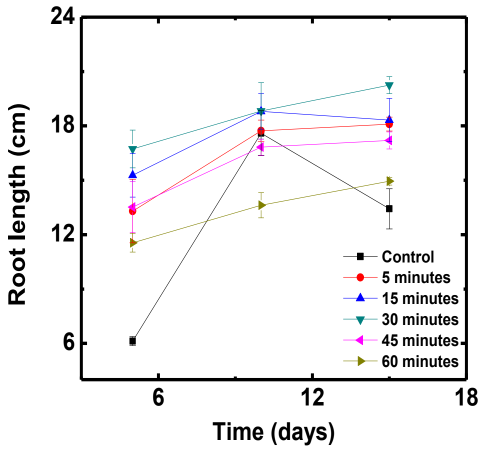

Fig 9: Changes of mung bean root length for 15 days

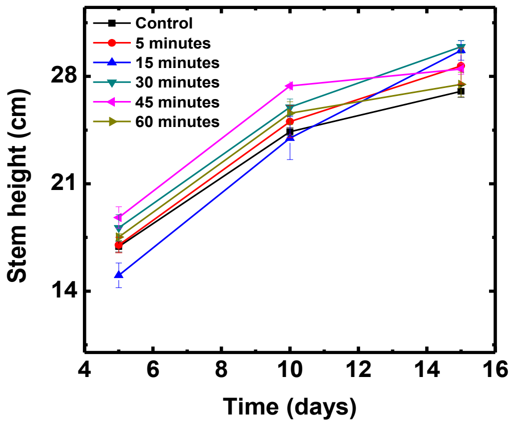

Fig 10: Changes of mung bean Stem height for 15 days

In several studies, corona glow discharge plasma has been used to accelerate germination and plants growth [17], [18]. Nucifera et. al. was utilizing plasma corona to accelerate black soybeans. The black soybeans seeds were planted for 30 days

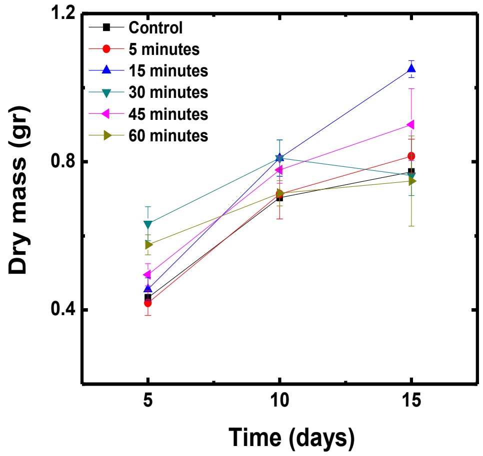

Fig 11: Changes of mung bean dry mass weight for 15 days

The result indicated that the percentage of germination for seeds with plasma radiation for 30-minutes time irradiation reaching 314.28% compared to the sample cluster that not given plasma radiation. The results of applying coronal plasma through the interaction of cold plasma species with the seed surface show accelerated growth. The important thing that can be taken is the latest progress in the field of agricultural plasma. Although plasma farming is a relatively new research field, and the complex interaction mechanisms are not yet fully understood, it holds great promise for the future. This study is a direct treatment of plasma species with seeds. Indirect treatment has also been tried for agricultural plasma by producing nitrate in liquid fertilizer. The application of cold plasma at atmospheric pressure for agriculture will further enrich this field for the future.

4. Conclusion

We have successfully accelerated mung bean growth plants by corona glow discharge plasma and measured the ion mobility value on mung bean seeds. The voltage and current discharge to ignite plasma corona are 3.6 kV and 20.5 μA respectively, and electrodes are divided in a range 2 cm as optimal distance to produce plasma corona. The average of ion mobility value is 1.87 ± 0.21 which is only between grades 1 to 3. We found that plasma corona is extremely influence the growth of mung bean plants. During 15 days cultivation, the changes of root, stem, leaf, and dry mass were considerably increases compared to control plants, while the content of carbohydrate, and protein slightly rises. For irradiation time of 15 minutes and 30 minutes show the most substantial increase compared with the other time treatment. In addition, the longer irradiation time of the mung bean plants growth were slow. Furthermore, the nitrogen content shows the best result is irradiation for 30 minutes with 3.57%. For the entire experiments, it shown that corona glow discharge plasma is applicable to accelerate plants and improve the quality of mung bean.

Acknowledgements

This research partially was supported by Universitas Diponegoro, Indonesia, through the RPI (No. 569-126/UN7.D2/PP/VII/2022). Authors would like to acknowledge the supports given by research assistants of Centre for Plasma Research, Diponegoro University

References

[1] N. N. Misra, O. K. Schluter, and P. J. Cullen, Cold Plasma in Food and Agriculture, Elsevier (2016).

[2] M. Selcuk, L. Oksuz, and P. Basaran, Decontamination of grains and legumes infected with Aspergillus spp. and Penicillum spp. by cold plasma treatment, Bioresour. Technol, 2008, vol. 99, no. 11, pp. 5104–5109.

[3] M. Nur, I. W. Nugroho, and Z. Muhlisin, Nitrogen production on corona glow discharge plasma multipoint plane configuration and the use of nitrogen on compost, Sci. Math. J., vol. 19, no. 2, pp. 60–64,(2014).

[4] D. P. Park, K. Davis, S. Gilani, C. A. Alonzo, D. Dobrynin, G. Friedman, A. Friedman, A. Rabinovich, and G. Fridman, Reactive nitrogen species produced in water by non-equilibrium plasma increase plant growth rate and nutritional yield, Curr. Appl. Phys.,2013, vol. 13, no. SUPPL.1.

[5] H. R. Boenig, Fundamentals of Plasma Chemistry and Technology, Lancaster: Technomic Publishing Company, (1988).

[6] T. Ito, T. Kawamura, A. Nakagawa, S. Yamazaki, B. Syuto, and K. Takaki, Preservation of fresh food using AC electric field, Isehd,2014, pp. 2–5

[7] N. Hayashi, R. Ono, M. Shiratani, and A. Yonesu, Antioxidative activity and growth regulation of Brassicaceae induced by oxygen radical irradiation Antioxidative activity and growth regulation of Brassicaceae induced by oxygen radical irradiation, 2015, vol. 1, pp. 2–7

[8] K. Koga, S. Thapanut, T. Amano, H. Seo, N. Itagaki, N. Hayashi, and M. Shiratani, Simple method of improving harvest by nonthermal air plasma irradiation of seeds of Arabidopsis thaliana (L.), Appl. Phys. Express, 2016, vol. 9, no. 1,

[9] W. Li, C. Shu, P. Zhang, and Q. Shen, Properties of Starch Separated From Ten Mung Bean Varieties and Seeds Processing Characteristics, Food Bioprocess Technol, vol. 4, no. 5, pp. 814–821,(2011).

[10] S. Shanmugasundaram, J. D. H. Keatinge, and J. d'Arro. Hughes, The mungbean transformation: Diversifying crops, Defeating malnutrition, Ifpri, vol. 922, no. November, p. 52,(2009).

[11] H. H. Kadarmanto, Food Crop Production, Jakarta, (2015).

[12] R. S. Sigmond, Simple approximate treatment of unipolar space-charge-dominated coronas: The Warburg law and the saturation current, J. Appl. Phys., vol. 53, no. 2, pp. 891–898, (1982).

[13] S. Jiao, J. A. Johnson, J. Tang, G. Tiwari, and S. Wang, Dielectric properties of cowpea weevil, black-eyed peas and mung beans with respect to the development of radio frequency heat treatments, Biosyst. Eng., vol. 108, no. 3, pp. 280–291,(2011).

[14] M. Nur, A. H. Azzulkha, M. Restiwijaya, Z. Muhlisin, and Sumariyah, The Study of Electrohydrodynamic and Wind Ions Direction Produced by Positive Corona Plasma Discharge, Adv. Phys. Theor. Appl., vol. 30, pp. 55–65, (2014).

[15] I. Filatova, V. Azharonok, V. Lushkevich, A. Zhukovsky, G. Gadzhieva, and K. Spasi, Plasma seeds treatment as a promising technique for seed germination improvement, in 31st International Conference on Phenomena in Ionized Gases, pp. 4–7, (2013).

[16] B. Šerá, P. Špatenka, M. Šerý, I. Hrušková, and A. S. Materials, Influence of Plasma Treatment on Wheat and Oat Germination and Early Growth, IEEE Trans. Plasma Sci.,2010, vol. 38, no. 10, pp. 2963–2968

[17] S. Lynikiene, A. Pozeliene, and G.

Rutkauska, "Influence of corona discharge field on seed viability and dynamics of germination, Int. Agrophysics, 2006, pp. 195–200,
[18] N. Nucifera, M. A. J. Kanie, S. H. Pratiwi, R. Pratiwi, S. Putro, and M. Nur, Corona discharge plasma technology to accelerate the growth of black soybean plants, J. Nat. Sci. Res., July, (2016).
[19] F. Jalu, N. Putra, Z. Muhlisin, and S. P. Putro, Treatments of plasma corona radiation on seaweed gracilaria verrucosa (Hudson) papenfuss: Efforts to increase growth and biomass, Int. J. Sci. Eng.,2015, vol. 8, no. January, pp. 75–79
[20] Pia Stariˇ Katarina Vogel-Mikuš, Miran Mozeti and Ita Junkar, Effects of Nonthermal Plasma on Morphology, Genetics and Physiology of Seeds: A Review, *Plant,* 2020,9, 1736, pp. 1-18
[21] Renáta Švubová, L'udmila Slováková, L'udmila Holubová, Dominika Rovˇnanová, Eliška Gálová and Juliána Tomeková, Evaluation of the Impact of Cold Atmospheric Pressure Plasma on Soybean Seed Germination, *Plant,* 2021,10, 177, pp. 1-17