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Utilization of Plasma Technology to Control Weed Seed Germination

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Abstract

Efforts to reduce herbicide use include employing cold plasma technology, which produces heat energy from UV plasma rays using a combination of electrical power. This research aimed to determine the effectiveness of plasma technology in controlling weeds and to identify the optimal voltage and duration for using cold plasma technology to inhibit seed germination. The study was conducted at the Ecotoxicology Laboratory and Seed Propagation Laboratory of IPB in Bogor, Indonesia, from January to March 2023. It comprised two experiments: (1) testing the voltage and time duration of cold plasma technology and (2) examining the effect of electrode needle distance on mustard seeds. The first experiment followed a completely randomized design with plasma voltage and time duration as the treatments. The second experiment used a single-factor completely randomized design to investigate the electrode needle distance. Each experiment included four replications. The results indicated that a voltage of 140 kV with a duration of 80 seconds could suppress mustard seed germination by up to 100%. Additionally, using an electrode needle distance of 0.5 cm reduced the germination percentage of mustard seeds by up to 100% at 7 and 14 days after treatment.

Keywords: cold plasma, heat energy, Herbicide reduction, seed treatment, UV light.

Introduction

Herbicide use in Indonesia is increasing due to its practicality, speed, and cost-saving benefits. From 2017 to 2021, herbicide usage rose from 1,037 tons to 3,634 tons, with 2,145 registered herbicide brands nationally (Directorate General of PSP, 2021). This rise is attributed to workers opting for faster, more cost-effective solutions that save on working time and labor costs (Arvianti et al., 2019).

Manual weed control methods are deemed inefficient and impractical, requiring significant time, energy, and higher labor costs (Marliah et al., 2018). On average, it takes two to three workers around 7 to 8 hours per hectare to manually control weeds in rice fields (Hamidah et al., 2015).

The use of herbicides is economical for farmers (Supartama et al., 2018) but has significant negative impacts on the environment and the health of workers. These negative impacts include environmental pollution, which can contaminate nearby water systems (Widaryanto et al., 2021), disrupt physiological processes in animals, cause poisoning in sprayers (applicators), and lead to the resistance of weed species to herbicides (Aditiya, 2021). Farmers often experience symptoms such as headaches, vomiting, itchy skin, and in severe cases, death (Marliah et al., 2018). Given these risks, there is a need for alternative methods to reduce herbicide use, minimize environmental pollution, and prevent worker poisoning. One promising method is the use of cold plasma technology.

Cold plasma technology results from the use of various types of energy, such as electricity, thermal energy, UV light, and visible light, to ionize gas (Misra, 2015). When high energy is applied to a gas, it transforms into plasma, which contains high-energy electrons, ionized molecules, and UV photons (Chen et al., 2019).

The working mechanism of cold plasma technology involves providing high heat energy from electricity and producing reactive oxygen species (ROS), which inhibit systemic effects on seeds and plants (Ebadi et al., 2019). Cold plasma can inhibit seed germination, leading to seed deterioration (Shelar et al., 2022).

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When cold plasma, connected to a high voltage source, touches a plant, the high voltage flow and the heating effect of the electric current damage plant tissue, ultimately causing plant death (Diprose and Benson, 1984). The use of cold plasma technology can suppress weed growth, thereby reducing costs and labor associated with weed control. To achieve effective weed control using plasma technology, research is needed to determine the optimal plasma voltage and duration. This research aims to identify the appropriate plasma voltage and duration to control weeds during the pre-growth phase.

Materials and Methods

The experiment was carried out from January to March 2023 at the Ecotoxicology Laboratory and Quality Testing Seed Storage Laboratory, IPB, Bogor, West Java. The materials used in the research were mustard seeds and filter paper. The tools used in this research are cold plasma technology, petri dishes, dropper pipettes, tweezers, and other supporting tools.

Experimental Design and Procedures

Experiment 1: Mustard seed germination at different voltage and treatment duration

The experimental design used was a factorial, completely randomized design with two factors. The first factor is voltage (A) and the time given (B). The voltage levels provided consist of 8 voltages, including 0, 20, 40, 60, 80, 100, 120 and 140 kV. The duration of the time (B) includes 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, and 80 seconds. This treatment was repeated four times; each experimental unit consisted of 10 petri dishes of mustard seeds.

Mustard seeds with have good viability and high germination rates were sown on petri dishes with filter paper. The mustard seeds were arranged on seeding filter paper media with 2.5 cm between the seeds and moisturized with 25 drops of water using a 3 ml pipette. One by one, the mustard seeds were given voltage treatment for the duration of time using cold plasma according to the dose given. Next, the petri dishes were transferred into a 30^{0}C germinator. Maintenance is carried out daily by watering using a pipette with a volume adjusted to the humidity conditions of the filter paper.

Experiment 2: Mustard seed germination at different distance from electrode needles

The levels of electrode needle distance consist of 0.5, 1, 1.5, 2, 2.5, 3, and 3.5 cm. This treatment was repeated four times, each experimental unit consisting of 10 petri dishes of mustard seeds.

Mustard seeds were germinated in petri dishes as described above. The seeds on petri dishes were given treatment by adjusting the electrode needle distances according to the treatment, using the voltage and time duration according to the results of the first experiment. Next, the mustard seeds were transferred to the germinator and maintained as described above.

Germination Analysis

Mustard seed germination was measured out at 7, 14 and 21 days after plasma technology treatment by calculating seeds' germination percentage (%). The germination percentage is calculated according to the following formula:

$$\text{Germination percentage} = \frac{\text{number of germinated seeds}}{\text{total seeds sown}} \times 100\%$$

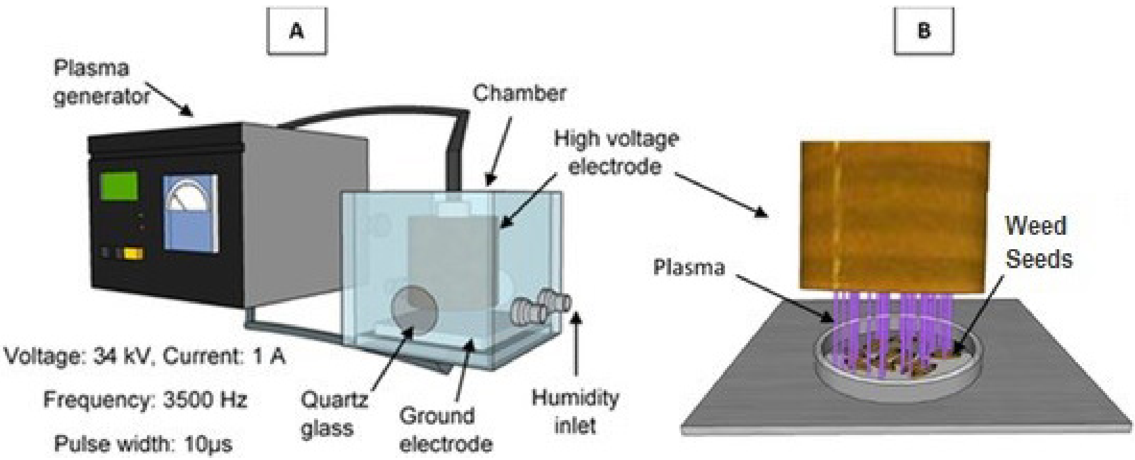

Figure 1. (a) Fluorescent regulator and transformer slide; (b) plasma electrode

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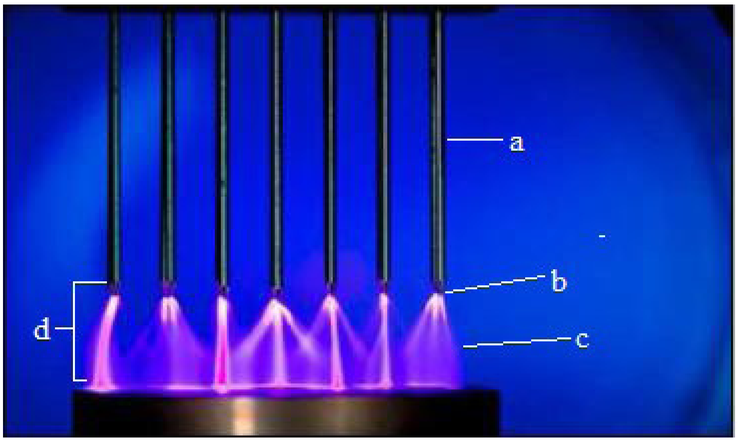

Figure 2. (a) Plasma electrode needles, (b) plasma electrode needle tip, (c) UV light, and (d) distance of needle tip to the seeds.

Results and Discussion

Mustard Seed Germination

The germination of mustard seeds decreased as the voltage and duration of the treatments increased (Figure 3). At a voltage of 140 kV with a duration of 80 seconds, mustard seed germination was reduced by up to 100% (Figure 3).

Reduction in germination occurs when the seed coat is damaged or burned due to increasing voltage (Adhikari et al., 2020). This finding aligns with research by Hayashi et al. (2014), which states that as the duration of cold plasma exposure increases, there is a natural inhibition of the hydrophilicity of the seed surface. This inhibition can be attributed to physical changes in the seed surface caused by plasma treatment (Brust et al., 2021). Conversely, cold plasma treatment with a small voltage and short duration might not reduce germination (Shau et al., 2013).

The germination percentage of mustard seeds treated with cold plasma technology varies across different treatments (Figure 4). At a voltage of 140 kV with time durations of 40, 45, 50, 55, 60, 65, 70, 75, and 80 seconds, results show that longer plasma exposure leads to a decrease in seed germination. The extended duration of cold plasma treatment negatively impacts the seeds' ability to germinate (Gao et al., 2019), primarily because the seeds fail to maintain good viability (Agurahe et al., 2019).

Seed viability is very low due to heat energy, which affects seed germination, preventing the seeds from initiating the germination process. Seed germination encompasses both germination power and germination rate. The application of cold plasma technology to seeds can reduce both germination capacity and germination rate (Pérez-Pizá et al., 2020). As a result, the seeds' ability to effectively absorb water and nutrients is compromised.

The effectiveness of cold plasma technology also depends on the distance of the electrode needle that produces UV light. The distance of the electrode needle affects the germination percentage results. The experiment on electrode needle distance (Figure 5) shows that a distance of 0.5 cm is effective in inhibiting mustard seed germination at 7 and 14 days after treatment. At this distance, mustard seeds showed no germination on day 7, which persisted until day 14.

The reduced seed germination is likely due to UV rays producing heat energy at a close distance to the mustard seeds. The electron bombardment resulting from UV light inhibits the potential for seed germination (Waskow et al., 2021). Electrons produced from high voltage release heat energy (Machala et al., 2018). Satoshi et al. (2012) stated that cold plasma treatment on seeds disrupts seed hydrophilicity, hampering the seeds' ability to absorb water and nutrients, thereby inhibiting seed growth.

Discussion

Cold plasma technology is not yet widely utilized in agriculture, particularly as a weed control tool, and this experiment represents an early stage in its application. Weed control aims to restrict weed growth to minimize competition with primary crops (Umiyati and Widayat, 2017). Traditionally, farmers rely on chemical methods to control weeds, which can pose environmental risks. In contrast, cold plasma technology has been shown not to have a negative impact on the surrounding environment (Pankaj et al., 2018).

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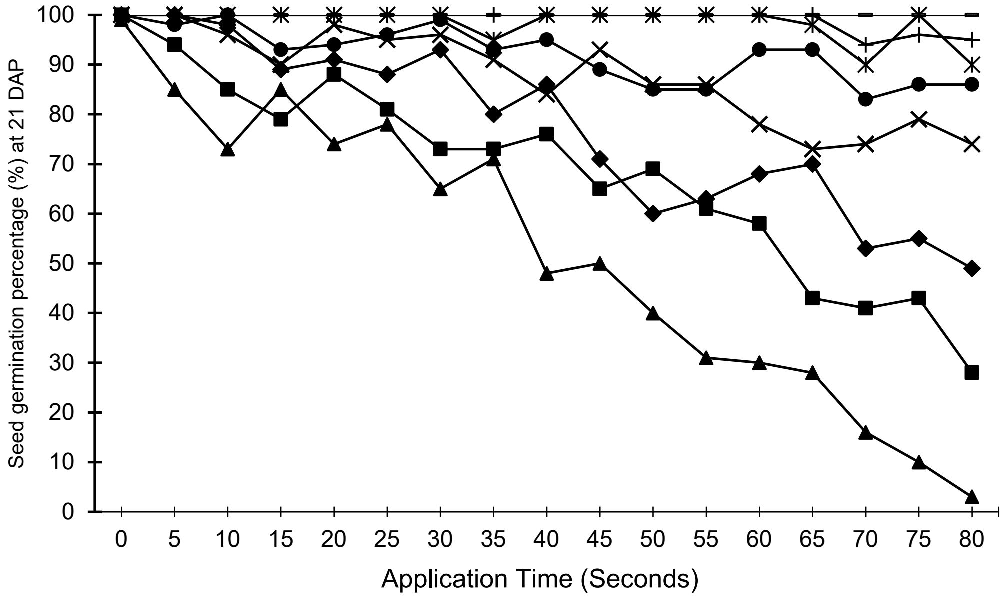

Figure 3. Effects of voltage dose and treatment duration on mustard seed germination. (-) CP0 = Control, (+) CP2 = 20 kV, (*) CP4 = 40 kV, (●) CP6 = 60 kV, (x) CP8 =80 kV, (♦) CP10 = 100 kV, (■) CP12 = 120 kV, (▲) CP14 = 140 kV. DAP = days after treatment.

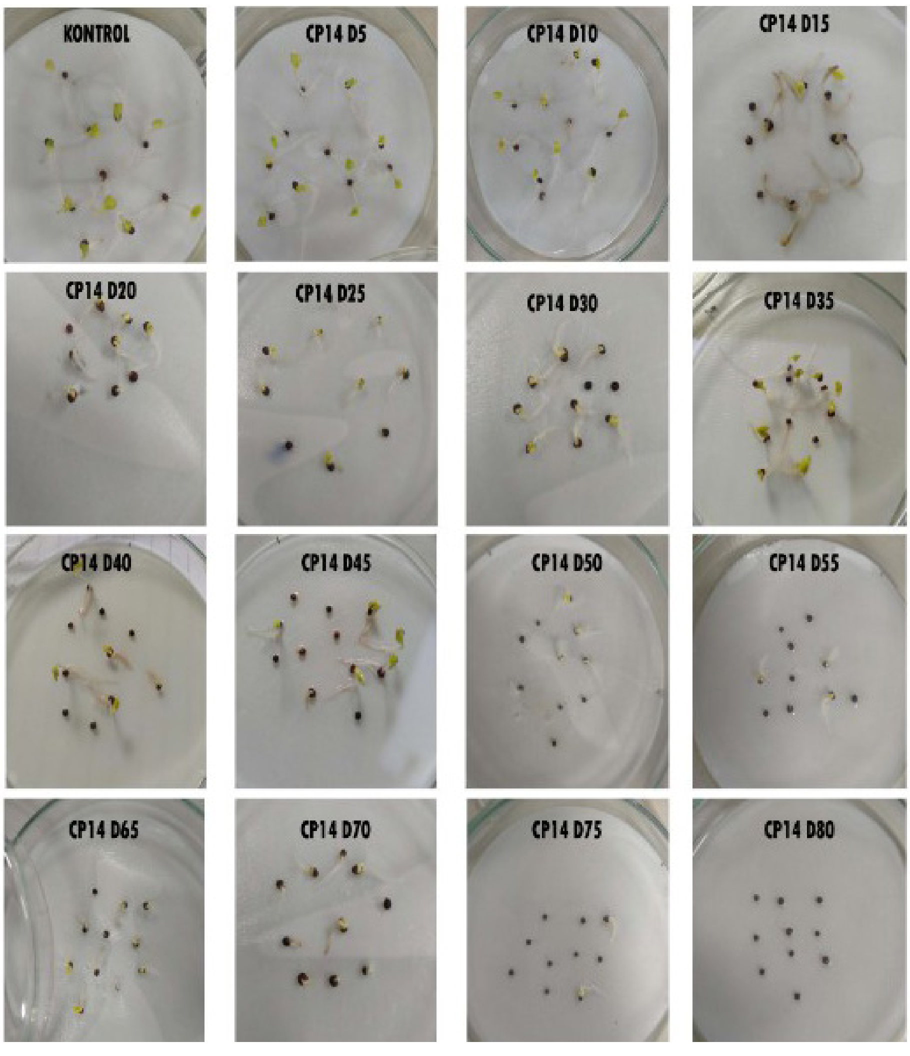

Figure 4. Mustard seed germination at 21 days after treatment with a dose of 140 kV at various durations.

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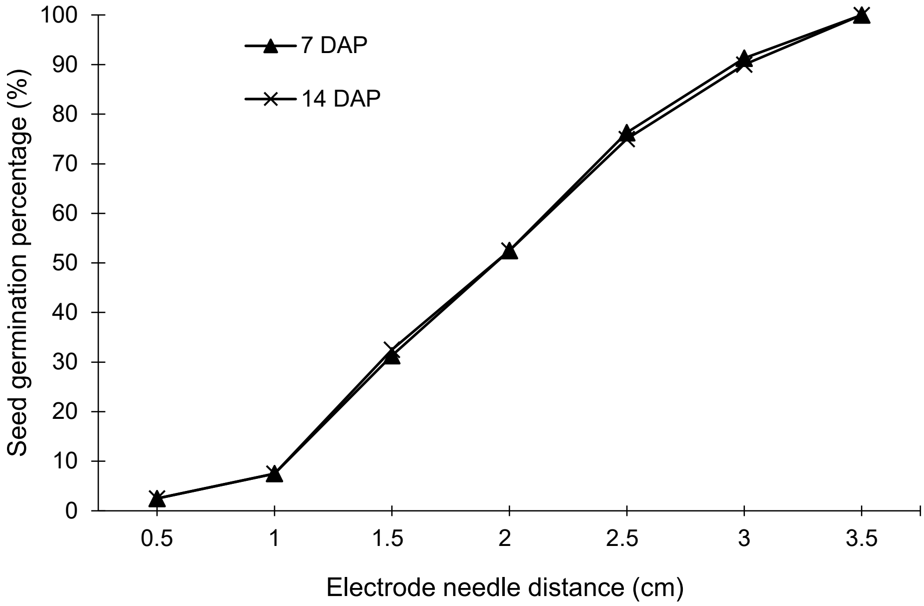

Figure 5. Mustard seed germination at different distance of electrode needles of the plasma technology. DAP= days after treatment

Cold plasma technology has the potential to reduce herbicide use for weed control, especially during the post-emergence phase. However, significant optimization is necessary before this technology can be scaled up for widespread use. One potential application of cold plasma technology in future weed control efforts involves integrating it with agricultural machinery, such as tractors. During soil tilling operations, weeds emerging above the ground could be exposed to UV light and heat energy from cold plasma technology, thereby hindering the growth of weed seeds before they can establish themselves.

Conclusion

Cold plasma technology treatment at a voltage of 140 kV and duration of 80 seconds, with an electrode needle distance of 0.5 cm, effectively inhibits mustard seed germination by up to 100% at 7 and 14 days after treatment. Further studies are necessary to explore the potential of this technology for weed control on a larger scale.

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