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The Comparison of Wheat Growth Indicators Under the Influence of Different Treatments of Cold Plasma and Plasma-Activated Water

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ABSTRACT

In this paper, the direct effects of gliding arc discharge (GAD), dielectric barrier discharge (DBD), and argon plasma jet (APJ) discharge as generators of reactive oxygen and nitrogen species (RONS) on wheat seed yield have been evaluated. This evaluation was conducted for a period of eight months in fall planting. The plasma-activated water was used for irrigation during this period. Physical quantities of the plant, such as length, weight as well as panicle length, neck diameter, weight, number of seeds per panicle, and grain weight were measured. Appropriate comparisons were made on the measurements. The results indicated that cold atmospheric pressure plasma increased plant length and biomass. Moreover, the length and diameter of the panicle also increased which resulted in a relative increase in the number and weight of seeds. Therefore, it can be claimed that cold plasma has a positive effect on the growth and reproduction of wheat.

Keywords: Argon Plasma Jet; Dielectric Barrier Discharge; Gliding Arc Discharge; Wheat

1. Introductions

Neutral ionized gas forms the nature of plasma, which is the fourth state of matter [1]. It is composed of highly reactive ions, electrons, atoms, and radicals that can alter any molecular structure [2]. Plasma has wide and diverse applications in agriculture, medicine, environment, and industry and has attracted too much attention as an emerging technology with high potentiality for remediation of contaminated soils and water [3],

microbial decontamination of food products and surfaces [4], detoxification of agricultural products [5], and an increase in seed germination and seedling growth [6]. Compared to other methods, plasma has the advantages of safety, compatibility with the environment, low cost, and short treatment time.

In the process of plasma discharge in the air, nitrogen and oxygen are broken down by high-

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energy electrons and different species of oxygen and nitrogen such as OH, O₃, NO, NO₃⁻, and NO₂⁻ are produced. Plasma effects on materials are primarily caused by reactive oxygen and nitrogen species with short and long lifetimes [3-8]. Plasma treatment leads to changes in the physical and chemical properties of the seed surface, an increase in its hydrophilicity and therefore water absorption. An increased water absorption is accompanied by an increased intake of nutrients and oxygen. Water uptake leads to the activation of enzymes converting complex and insoluble food reserves into simpler, soluble compounds which can be used by seeds to produce the energy needed for germination. Another effect of cold plasma is to increase the growth and density of plant roots per unit area, so that the plasma-affected seeds develop their roots further. As a result, the contact surface area of the roots with soil particles is increased which results in an increase in absorption of water and nutrients. Plasma can also remove microbial contaminants from the seed surface [9-12]. Therefore, plasma by increasing the seed germination and seedling growth via altering the seed wetting property, seed surface sterilization, and improving plant metabolism can play an effective role in enhancing agricultural products to meet the food demand of the growing world population [1].

In this study, wheat seeds were treated using three different types of plasma generators. Since the amount and type of the reactive species formed in each plasma generator depend on parameters such as voltage, frequency, power, and geometry of the plasma generator, it is expected that their effect on wheat seed treatment will yield different results. In addition, to supply the required nitrogen to the plant, plasma-activated water with electric discharge plasma was used for irrigation.

2. Materials and Methods

2.1. Plasma generators for the treatment of the wheat seed

The following three methods were conducted for the treatment of wheat seed: Gliding Arc Discharge (GAD), Dielectric Barrier Discharge (DBD), and Argon Plasma Jet (APJ).

2.1.1. Gliding Arc Discharge (GAD)

The atmospheric pressure plasma (APP) based on gliding arc discharge (GAD) is formed when a high electric potential (a few kilovolts) is applied between two metal electrodes (without any insulation). When this voltage is applied, strong sparks and arc discharges are formed. The flow of a gas, which is often air, expands on the electric discharge zone after the sparks are formed, and prevents the electric discharge zone from overheating. In this experiment, a power supply with a variable voltage of 0-15 kV and a sine frequency of 50 kHz was used to produce the discharge. The schematic set-up of the system is illustrated in Figure 1.

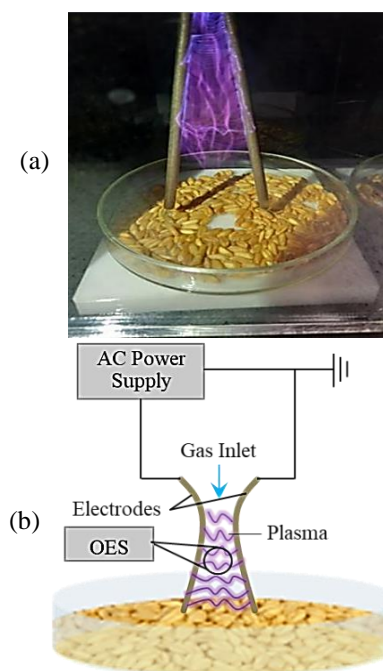


Fig. 1. a) Picture, b) Schematic of Gliding Arc Discharge system.

2.1.2. Dielectric Barrier Discharge

In dielectric barrier discharge (DBD) (Figure 2), one or both electrodes are coated with an appropriate insulator and are connected to two metal electrodes with an electric potential of 15 kV and sine frequency of 50 kHz. The electrodes consist of two circular plates with the lower electrode coated with 3mm thick Pyrex.

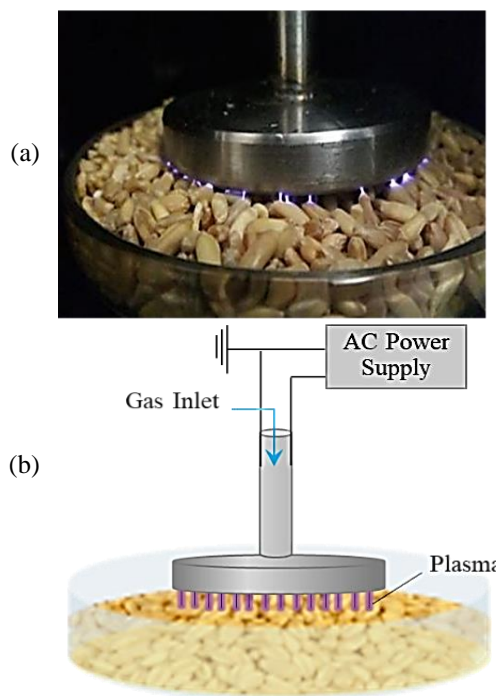


Fig. 2. a) Picture, b) Schematic of Dielectric Barrier Discharge system.

2.1.3. Argon Plasma Jet

In an argon plasma jet (APJ) a high-voltage field affects the gas flow and generates plasma. The electric field is generated across an electrode by a power supply with a voltage of 15 kV and a sine frequency of 50 kHz, resulting in the generation of plasma from argon gas. Reactive oxygen and nitrogen species (RONS) are generated by the collision of electrons from electric discharge with air molecules (Figure 3).

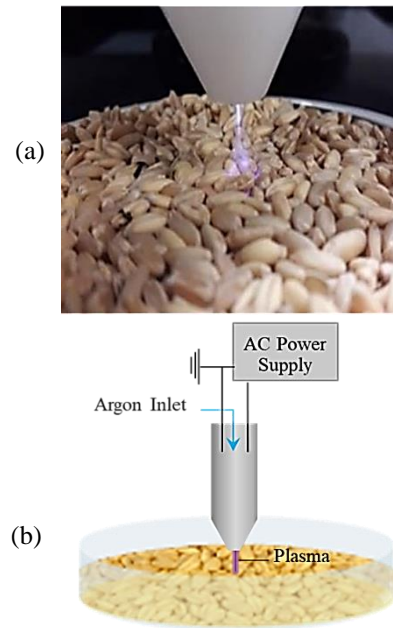


Fig. 3. a) Picture, b) Schematic of Argon Plasma Jet system.

2.2. Plasma-activated Water Generators

To produce plasma-activated water, an electrode bar placed over the water surface and connected to a high-voltage power supply produces reactive oxygen and nitrogen species by creating plasma on the surface of the water which is circulated inside a container by a pump. Water is treated with plasma for 20 minutes each time before being used for irrigation (Figure 4).

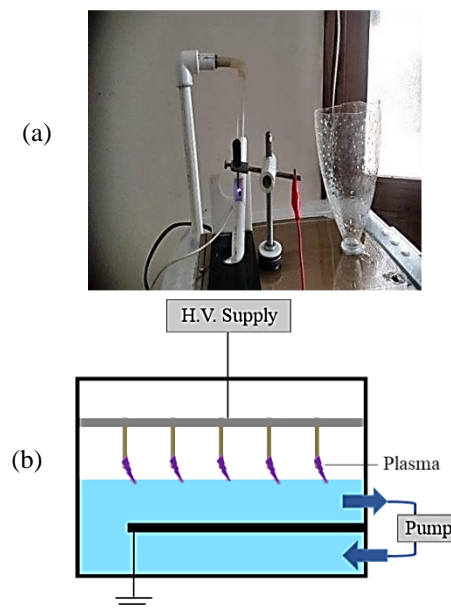


Fig. 4. a) Picture, b) Schematic of Plasma-Activated Water system.

2.3. Plant Materials and Plasma Treatment

Wheat seeds of Mehregan cultivar were provided by Agriculture-Jihad Organization. 100 grams of seeds were weighed for each treatment (GAD, DBD, APJ, and control) and then were placed in Petri dishes to be treated for 4 minutes.

2.4. Cultivation Conditions

Four pots, each one with length and width of 1 m and a height of 40 cm and their supporting bases were designed and built for wheat cultivation (Figure 5). Then, based on the dimensions of the pots, 32 grams of seeds were planted in pots containing equal amounts of soil, sand, and animal manure for each treatment. Pots were in a completely randomized design with three replications in ambient air from November 2019 to June 2020 in the temperature range of 5-25 C. Untreated water was used to irrigate the control plant, while pots containing plasma-treated seeds were irrigated several times during the experiment with the same amount of water – plasma-activated water. Plants were harvested after germination and after reaching their final stages of growth (Figure 6). Subsequently, the parameters of plant length (from the soil surface to the tip of the panicle), plant diameter, plant weight, panicle length, panicle diameter, panicle weight, number of seeds per panicle, and grain weight were measured.



(a)

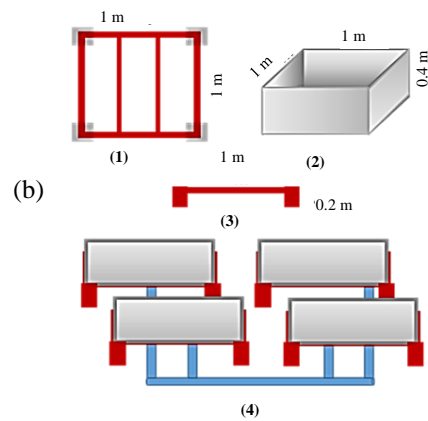


Fig. 5. a) Picture of vases, **b)** Schematic of vases: (1) Top view of the base that holds and separates the container from the floor, (2) Container with a length and width of 1 meter and a height of 40 cm, (3) Side view of the base with a height of 20 cm from the floor and (4) The pots are placed in such a way that the pipes under the containers are for draining excess water from the pots.

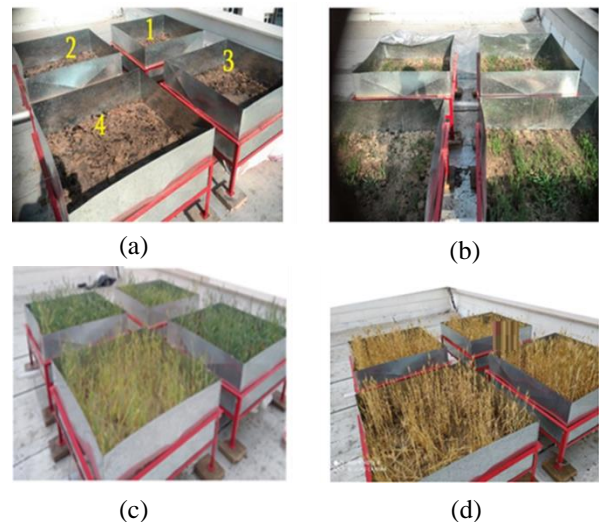


Fig. 6. a) Planting stage of wheat seeds with 15 minutes treatment: Pot 1 of DBD treated seeds, Pot 2 of APJ treated seeds, Pot 3 of GAD treated seeds, and Pot 4 of control seeds. **b)** Picture of wheat growth on November 14, **c)** Picture of wheat growth 1 month before harvest, **d)** Wheat harvest.

2.5. Statistical Analysis

This experiment was performed in a completely randomized design with Anova analysis of variance and data analysis was performed with SAS software.

3. Results and Discussion

Using one of the systems, the effect of different treatment times was investigated for seed germination and finally, the optimal time of four min was obtained (data not mentioned). Also, in order to determine the type of species produced in plasma, optical emission spectroscopy (OES) was performed (Figure 7).

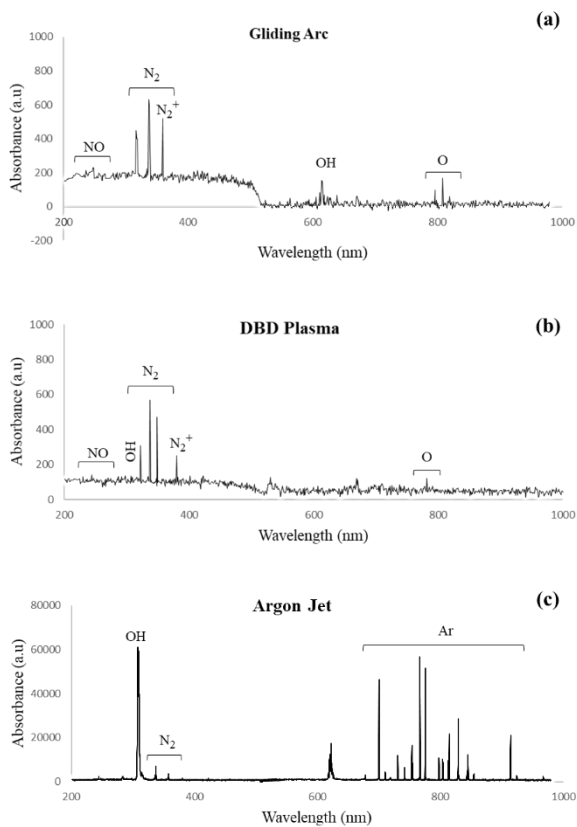


Fig. 7. OES spectrum for a) Gliding Arc, b) DBD, c) Argon Jet.

The results of measuring the phenotypic traits of wheat are as follows:

3.1. Plant Length

There was a significant difference in mean plant length between control and plasma-treated samples and plasma treatment increased plant length. The highest increase was due to GAD treatment, which increased by about 26.5%, while there was no

significant difference between DBD and APJ treatments.

3.2. Stem Diameter

There was a significant difference between control and plasma-treated samples, while the different plasma treatments did not show a significant difference. Plasma treatment increased stem diameter by about 10%.

3.3. Plant Weight

No significant difference was observed between plasma-treated and control samples. Therefore, plasma treatment had no effect on plant weight (Figure 8).

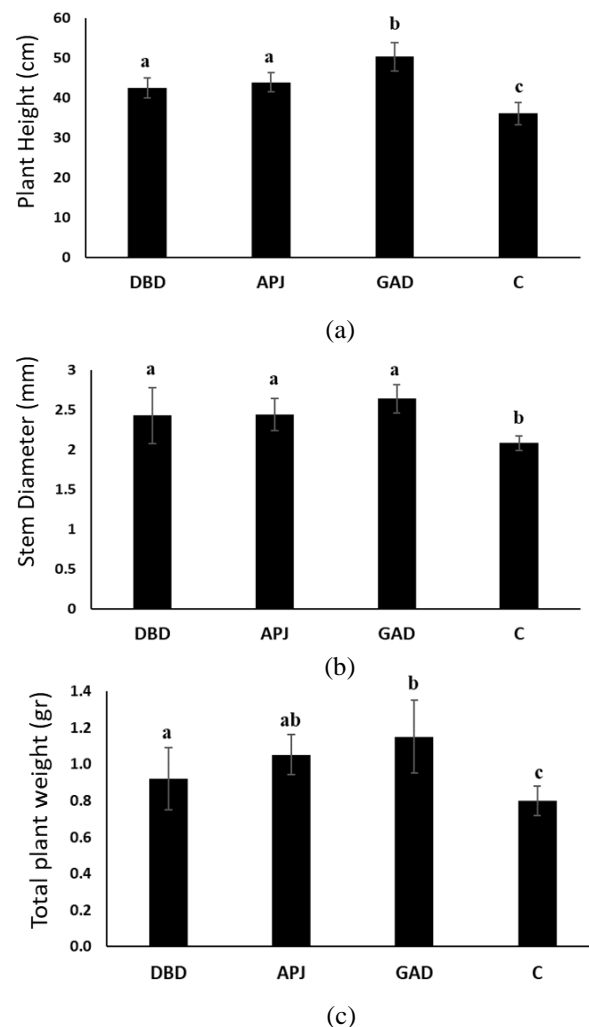


Fig. 8. a) Plant length, b) Stem diameter, c) Plant weight.

3.4. Panicle Length

All three plasma treatments increased the panicle length compared to the control samples. There was no significant difference between APJ and DBD treatments, while more increase in panicle length was observed in GAD treatment.

3.5. Panicle Weight

A significant difference was observed between plasma-treated and control samples while there was no significant difference between APJ and DBD treatments. More increase in panicle weight was observed in GAD treatment.

3.6. Grain Number

No significant difference was observed between DBD plasma-treated and control samples. However, APJ and GAD plasma treatments led to a significant increase in the grain number as compared to control samples.

3.7. Grain Weight

A significant difference between plasma-treated and control samples was observed and the plasma treatments increased the grain weight (Figure 9). Plasma treatment of wheat with different plasma systems showed positive effects on seed germination and plant growth, for example by applying atmospheric pressure gliding arc discharge plasma systems [13]. concluded that plasma changes the performance and architecture of the wheat seed surface. The 6-minutes treatment increases the germination rate by more than 95%, and the 30- and 90-minute treatments increase the length and number of spikes. Lotfy et al. [14] reported that the effects of nitrogen atmospheric plasma jet on growth parameters depend on exposure time. They showed that the average of sprout fresh weight for treated seeds was 823.82 mg, which increased to 1231.80, 1369.50, and

1342.46 mg for 2-, 4-, and 6-minute treatments, respectively. Also, plasma treatment with a dielectric barrier discharge system in the optimal dose had positive effects on wheat seed germination, seedling growth, shoot length, root length, and dry and wet weight [15].

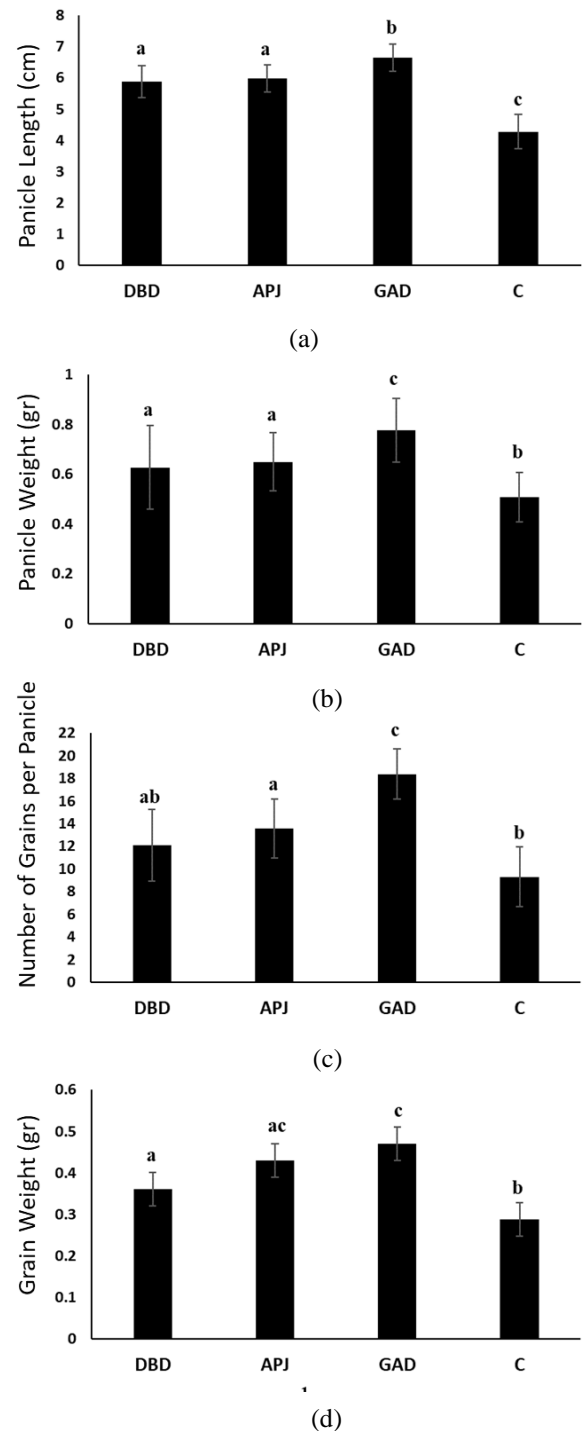


Fig. 9. a) Panicle length, b) Panicle weight, c) Number of seeds per panicle, d) Seed weight.

4. Conclusion

Plasma is the fourth fundamental state of matter which includes electrons, positively charged ions, radicals, gas atoms, molecules (in the ground or excited state), and photons [16]. Cold atmospheric plasma chemistry is the foundation of plasma agriculture. Plasma can be used in combating biotic stresses, resisting abiotic stresses, sterilizing food during storage, and also improving germination speed. Active oxygen and nitrogen species present in plasma can initiate messaging pathways in the plant, the result of which is the activation of some transcription factors and changes in gene expression and consequently changes in metabolism and plant traits [17].

The results of applying cold plasma treatment using three GAD, DBD, and APJ systems in this study indicated that in terms of vegetative traits, the plasma from all three systems had an increasing effect on plant length and was effective in increasing plant diameter, whilst all three systems had an increasing effect on plant weight.

Therefore, plasma has caused an increase in biomass. Regarding the reproductive traits, in addition to the increase in the length and diameter of the panicle by all three plasma systems, positive changes in the weight of the panicle and seed have also been observed. Therefore, it can be said that plasma has a positive effect on the growth and reproduction of wheat.

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