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INFLUENCE OF DIELECTRIC BARRIER DISCHARGE PLASMA ON *LEPIDIUM SATIVUM* SEEDS GERMINATION

O. Nedybaliuk, Ye. Ihnatenko, Iu. Kovalenko
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
E-mail: oanedybaliuk@knu.ua

The effect of dielectric barrier discharge (DBD) treatment on the germination of *Lepidium sativum* seeds under different conditions was investigated: dry and wet seeds. The emission spectra of the DBD plasma were measured. The rotational (T_r) and vibrational (T_v) temperatures of the DBD plasma are determined from the N_2 bands. The dependences of the germination percentage of *Lepidium sativum* seeds at different time intervals of DBD treatment were obtained. The optimal time for treating *Lepidium sativum* seeds was determined for dry and wet seeds.

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INTRODUCTION

One of the goals of sustainable development is to eliminate world hunger [1 - 2]. The control of plant diseases is essential for sustainable food crop production [3 - 4]. Many plant disease management strategies have played significant roles in reducing the frequency and intensity of diseases. However, 20…30% loss of crop production still occurs annually because of plant diseases. Under the current circumstances, traditional disease management strategies have often shown limitations in control efficiency and have multiple drawbacks. Chemical-based methods are most frequently applied for plant disease control; however, the emergence of pathogen resistance and environmental pollution make this strategy less reliable. The induction of plant resistance through species breeding and genetic engineering has been considered as a stable and long-lasting method for plant disease control. Public view on genetically modified organisms is still a barrier for popular use [3].

Fungi on seeds can affect the quality of the crop and cause spoilage and damage to the embryos during storage. They can infect food grains, producing toxins that cause diseases in humans or animals using these grains as food [5].

One method to prevent fungi's negative impact on plant growth and storage is plasma treatment [6]. Nonequilibrium atmospheric pressure plasma has many applications in various fields, such as surface treatment, combustion enhancement, bacterial inactivation [6 - 8], and contamination reduction [9]. Plasma is an effective sterilization method and can be used as an alternative to chemical seed disinfection [10]. One of the sources of nonequilibrium atmospheric pressure plasma can be a dielectric barrier discharge (DBD) [11].

This work is devoted to studying the effect of DBD treatment on the germination of *Lepidium sativum* seeds. The seeds of *Lepidium sativum* was chosen because it germinates quickly.

1. EXPERIMENTAL SETUP AND METHODOLOGY

Fig. 1 shows a schematic representation of a plasma system with a DBD designed for treating *Lepidium sativum* seeds before planting. The DBD system is made using a Petri dish lid. The bottom metal electrode (1) is placed on the lower plane of the glass lid. It is made of a copper wire in the form of a mesh placed on a 2 mm thick dielectric glass (2), which separates it from the upper metal electrode (3). The upper metal electrode is in the shape of a disk with a diameter of 30 mm and is made of copper. The disk is covered with a dielectric made of epoxy resin (4).

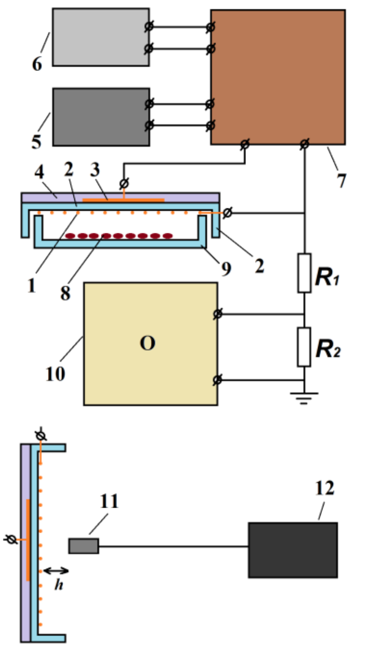


Fig. 1. Scheme of plasma system with DBD designed for treating Lepidium sativum seeds before planting: 1 – copper wire used as a lower metal electrode; 2 – dielectric; 3 – disk-shaped copper upper electrode; 4 – epoxy-based dielectric; 5 – DC power source; 6 – low-frequency signal generator; 7 – unit with transformer and amplifying circuit; 8 – seeds; 9 – Petri dish; 10 – oscilloscope (O); 11 – light guide; 12 – spectrometer; R_1 and R_2 – voltage divider resistors

The power supply of the dielectric barrier discharge consists of three units: a TES 13 DC power source (5), a GZ-109 low-frequency signal generator (6), and a unit containing a transformer and an amplifying circuit (7). The DC source (5) makes it possible to regulate the power of the dielectric barrier discharge in the range of 0…20 W. With the help of a low-frequency signal generator (6), the frequency can be adjusted within the 0…20 kHz range. The *Lepidium sativum* seeds (8) were treated in a Petri dish (9).

Voltage oscillograms were recorded by an oscilloscope (10) using a voltage divider made of resistors R_1 and R_2 (R_1:R_2 = 1000000:1). The effect of DBD plasma on seed germination was investigated using *Lepidium sativum* seeds as a model. During the experiment, atmospheric air was used as a feed gas for DBD. Fig. 2 shows typical DBD voltage waveforms. The discharge power was 6.3 W, and the frequency was set to 4 kHz using a low-frequency signal generator, which corresponds to the waveforms shown in Fig. 2. The presence of peaks on the envelope of the voltage signal is typical for a DBD.

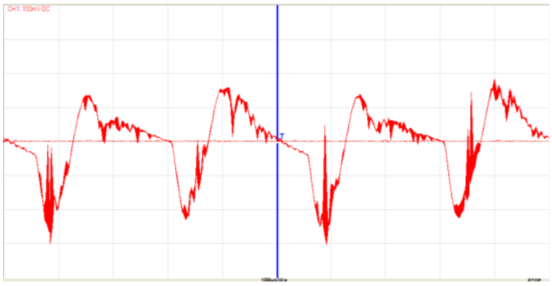
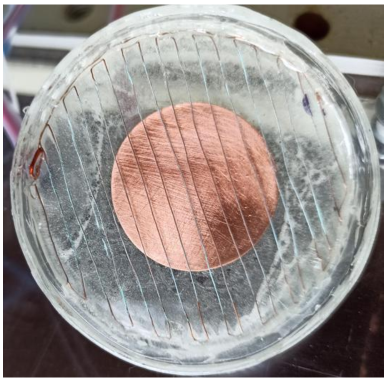


Fig. 2. Typical oscillograms of DBD voltage (timescales – 0.1 ms/div)

Optical emission spectroscopy of plasma radiation was carried out using an optical fibre (11), placed at a set distance *h* from the surface of the copper mesh, and a Solar TII S-150-2-3648 USB spectral device (12). The light guide was oriented along the beam of vision perpendicular to the surface of the glass plate on which a copper mesh was placed. Emission spectra were processed using a PC. The obtained optical emission spectra were used to determine the rotational (T_r) and vibrational (T_v) temperatures of nitrogen (N_2) in plasma. The temperatures were estimated by comparing the experimental optical emission spectra with the spectra simulated using the SpecAir 2.2 program [12]. More information about this method is available in our previous works [13 - 15].



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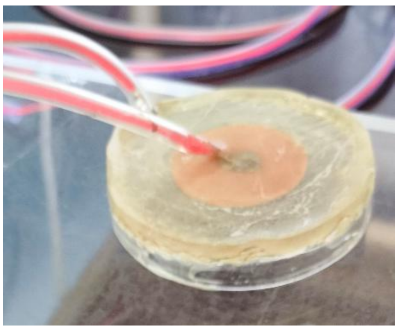

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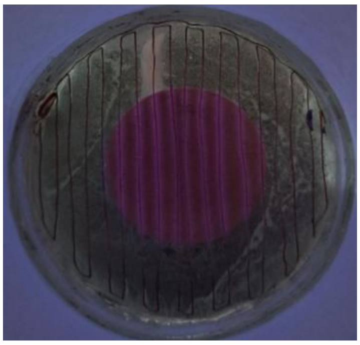

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Fig. 3. Photos of DBD electrodes system designed for treating seeds before planting: lower electrode (a); upper electrode covered with epoxy resin (b); DBD during operation (c)

Fig. 3 shows photographs of the DBD electrode system. Before the treatment with DBD, *Lepidium sativum* seeds were placed in a Petri dish, as shown in Fig. 4. The Petri dish was placed under the plasma system. The distance from the lower plane of the glass flange to the bottom of the Petri dish was 10 mm. The seed treatment time varied from 0 to 8 min with a step of 1 min.

Fig. 4. Photo of Lepidium sativum seeds placed in Petri dish before treatment with DBD

a

b

Fig. 5. Photo of typical container with soil-filled cells (a) in which both untreated and treated with DBD Lepidium sativum seeds (b) were planted

After the DBD treatment, the *Lepidium sativum* seeds were planted in special containers (Fig. 5,a) with soil-filled cells. A control group of untreated *Lepidium sativum* seeds was planted in the containers alongside treated seeds. Nine *Lepidium sativum* seeds were planted in each cell of the special container (Fig. 5,b). There were two regimes of DBD treatment, when *Lepidium sativum* seeds were dry and wet.

The containers with planted *Lepidium sativum* seeds (Fig. 6) were placed inside a box and illuminated with phytolamps during the workday (from 9:00 to 18:00). The room temperature was maintained at 20°C.

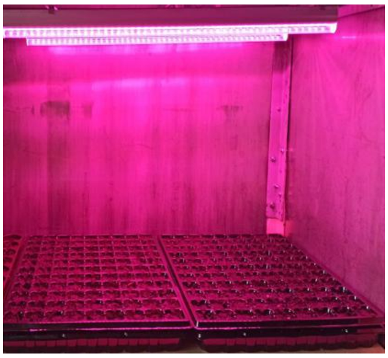


Fig. 6. Photo of a box where special containers with planted seeds were illuminated with phytolamps

Lepidium sativum seed germination was monitored 3, 7, 10 days after planting. After 10 days, germinated *Lepidium sativum* were dug up, washed with water, and their photographs were taken and analyzed.

2. RESULTS AND DISCUSSION

A typical plasma emission spectrum of a DBD with air as feed gas is shown in Fig. 7. The emission spectrum is composed chiefly of N_2 bands due to it being the main component of air. The appearance of the molecular N_2 band indicates that the rotational temperature is quite low compared to the rotating temperature of rotating gliding discharges [13 - 16].

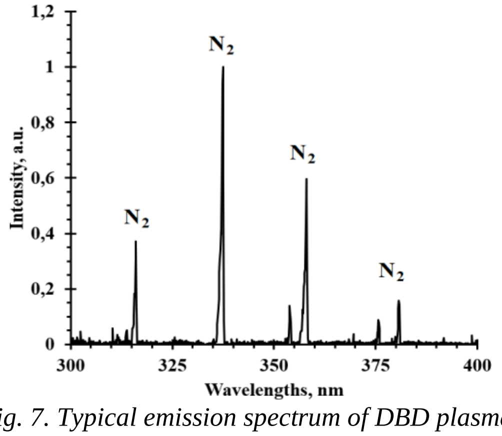


Fig. 7. Typical emission spectrum of DBD plasma: discharge power – 6.3 W; frequency – 4 kHz

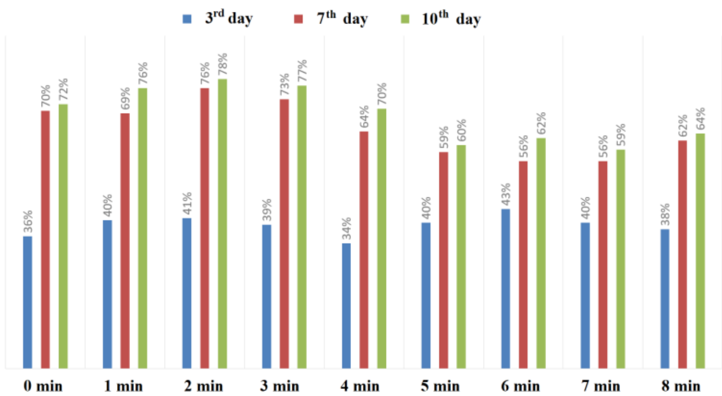
Rotational and vibrational temperatures of N_2 molecules in plasma were determined from the nitrogen N_2 bands by comparing the experimentally measured optical emission spectra with the ones simulated using the SpecAir 2.2 software [12]. The rotational temperature was T_r = 300 K, while the vibrational temperature was T_v = 2900 K. In the case of DBD, the rotational temperature is at the level of room temperature, unlike a rotating gliding discharge where the rotational temperature is an order of magnitude higher [16, 17], and treated seeds will not be burned due to thermal effects. The significant difference between the rotational and vibrational temperatures, which are almost an order of magnitude different, indicates the non-equilibrium of the DBD plasma.

Fig. 8 shows the percentage of germination of *Lepidium sativum* seeds measured on the 3rd, 7th and 10th day after planting under different operating modes of the plasma system with a DBD – dry and wet seeds. The power of the DBD was 6.3 W, the frequency was 4 kHz, and the treatment time varied from 0 to 8 min in 1-min increments. The control group was not treated and corresponds to a treatment time of 0 minutes. The germination of dry *Lepidium sativum* seeds (Fig. 8,a) in the case of DBD treatment for 1, 2 and 3 min is better than in the case of no treatment. In the case of dry *Lepidium sativum* seed treatment for 2 min, the percentage of *Lepidium sativum* germination seeds is higher than in the case of no treatment.

The germination of wet *Lepidium sativum* seeds (see Fig. 8,b) in the case of DBD treatment for 6 min is better than in the case of no treatment. When comparing wet seeds and dry seeds, the germination percentage of wet seeds is lower than that of dry seeds. This difference requires further investigation.

Fig. 9 shows the comparison of percentage of *Lepidium sativum* seeds germination without treatment (control) and with treatment by plasma of DBD on the 3rd, 7th and 10th day after planting when seeds were dry and wet before the planting.

Fig. 10 shows photos of the *Lepidium sativum* dug up on the 10th day after seeds planting. The same number of seeds was planted for each treatment time. Seeds that did not germinate or have become rotten were not photographed. The number of *Lepidium sativum* seeds that germinate in case treated with DBD plasma is higher than in case when seeds were not treated.



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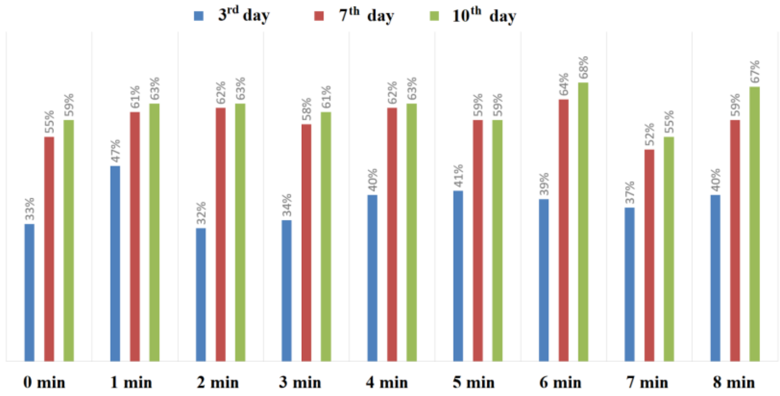

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Fig. 8. Dependence of percentage of Lepidium sativum seeds germination on the 3rd, 7th and 10th day after planting relative to the number of seeds planted for different time of DBD treatment: dry seeds (a); wet seeds (b)

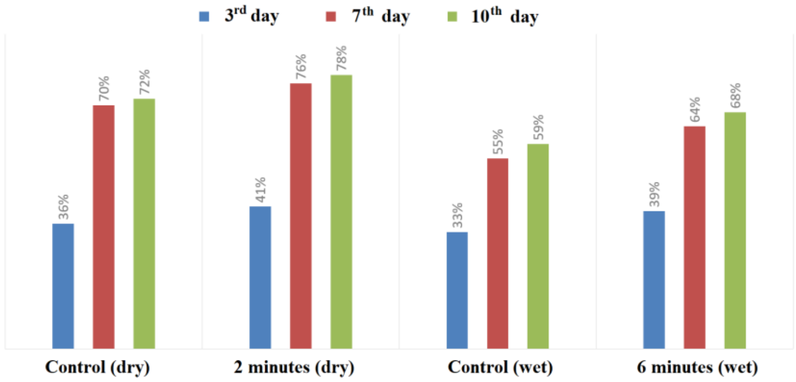

Fig. 9. Dependence of percentage of Lepidium sativum seeds germination without treatment (control) and with treatment by plasma of DBD on the 3rd, 7th and 10th day after planting when seeds were dry and wet

a

b

c

d

Fig. 10. Photo of Lepidium sativum stems on the 10th day: control (dry seeds) (a); 2 min (dry seeds) (b); control (wet seeds) (c); 6 min (wet seeds) (d)

These findings can significantly impact the agricultural sector, as the described treatment method is independent of logistics (all that is needed is air and electricity) and does not require the purchase of pesticides. Also, this method reduces harmful emissions into water (chemical industry waste) and air (waste from transportation), which, together with independence from the delivery of chemical treatments, is extremely important.

CONCLUSIONS

The influence of dielectric barrier discharge on the germination of *Lepidium sativum* seeds was investigated when seeds were dry and wet before the treatment.

The emission spectrum of the DBD plasma was measured, and N_2 was determined as its main component. From the emission spectra, the rotational and vibrational temperatures of N_2 were estimated. The rotational temperature was $T_r = 300$ K, that close to room temperature at 300 K, and vibrational temperature was T_v = 2900 K.

As of the 10th day after planting, the germination of the dry *Lepidium sativum* seeds treated with a DBD, regardless of the treatment time (in the range of 1 to 3 min), was better compared to untreated seeds. Regarding the percentage of germination, the optimal treatment time with a DBD of dry seeds was 2 min. When considering the development of the *Lepidium sativum* stem, the optimal time of DBD treatment is 2 min. Regarding the percentage of germination, the optimal treatment time with a DBD of wet seeds was 6 min. When considering the development of the *Lepidium sativum* stem, the optimal time of DBD treatment is also 6 minutes.

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ВПЛИВ ПЛАЗМИ ДІЕЛЕКТРИЧНОГО БАР'ЄРНОГО РОЗРЯДУ НА ПРОРОСТАННЯ НАСІННЯ *LEPIDIUM SATIVUM*

О. Недибалюк, Є. Ігнатенко, Ю. Коваленко

Досліджено вплив діелектричного бар'єрного розряду (ДБР) на проростання насіння *Lepidium sativum* за різних умов: вологого та сухого насіння. Виміряно емісійні спектри плазми діелектричного бар'єрного розряду. Визначено обертову (T_o) та коливну ($T_к$) температури плазми діелектричного бар'єрного розряду за смугами азоту (N_2). Побудовано залежності відсотку проростання насінин *Lepidium sativum* за різних проміжків часу обробки діелектричним бар'єрним розрядом. Визначено найбільш оптимальний час обробки насіння *Lepidium sativum* для сухого та вологого насіння.